P A R T - II

Page No.

/o0o0o0o0o0o0o0o0o/

PART - II

SECOND MAIN PAPER

(Sections C & D)

Page No.

S E C T I O N: D. (Contd.) Page No.

****
****
****
******
**

PREFACE

In the conventional methods of sewage purification, oxygen which is essential for oxidation of the putrid and decomposing organic matter is ordinarily obtained by mechanical means which involve huge capital, foreign equipment and considerable recurring costs for their maintenance and technical know-how. Most of the municipalities, and even municipal corporations in India are finding difficulties to provide money for these facilities, the cost of the final disposal works being the main deciding factor as to whether or not a city can undertake a sewerage system.

In recent years, however, a cheap, simple and natural process of sewage purification in lagoons or ponds has been evolved in western countries utilising solar energy for synthesising fresh algal cells which split water molecules as a part of their photosynthetic activity to produce the oxygen required. Algae which develop are those which are indigenous to the region and adapted to conditions imposed by the process in the locality. Thus, natural light energy is used to produce oxygen whose availability is independent of the physical laws normally governing oxygenation from atmospheric sources. Thus two basic types of reactions taking place together are oxygenation by algal photosynthesis and bacterial oxidation of the decomposing organic matter.

Single cell oxidation ponds have afforded such a degree of treatment in western countries that it is comparable to that attained with very efficient but costly conventional secondary aerobic treatment systems. The aerobic oxidation ponds are also stated to remove more than 90% of the Coliform flora and pathogenic bacteria of the Salmonella-Shigella group.

The possibilities of purification of Indian sewage by algal photosynthesis have not been adequately investigated although sufficient light energy is normally available anywhere in India. This method of sewage purification appears to be attractive, especially where finance is limited and the adoption of some form of treatment is most urgent as in Ahmedabad, where about 57 mgd. of sewage have to be treated. An attempt was, therefore, made to develop design criteria and criteria for operation of oxidation ponds trapping the energy of the sun at Ahmedabad through photosynthesis as the principal synthetic force for purifying the sewage of Ahmedabad. The ecology and seasonal succession of algae developing in the oxidation ponds investigated at Ahmedabad were also studied by the author during 1962 to 1963; and the results of the same form the subject matter of the second main paper.

The research studies made for the second paper are sub-divided into two sub-section C & D. Section C deals with the " ECOLOGY AND SEASONAL SUCCESSION OF ALGAE IN THE SINGLE CELL (Pilot Plant) OXIDATION POND AT AHMEDABAD"and Section D treats with the " ECOLOGY AND SEASONAL SUCCESSION OF ALGAE IN THE SEVEN CELL OXIDATION POND AT AHMEDABAD". In Section 'C' the author has studied the physical, chemical, bacteriological and biological conditions in the single cells pond of 3 acres in area and holding about 4 million gallons of sewage and has traced the inter-relationships between the algae developing during different seasons on the one hand and the ecological conditions on the other. In Section 'D' the ecological and seasonal succession of algae in a series of seven ponds have been studied for one year (1963) and a comparative study of the results obtained in a single unit as against a series of seven ponds with an area of about 24 acres and holding nearly 32 million gallons of sewage is made.

Two additional papers in support of the main paper have also been included. They are : (i) " Hydraulic loading and stablization of sewage by photosynthetic oxygenation " and (ii) " Bacterial Photosynthesis in the oxidation Ponds of Ahmedabad". The former deals with the degree of purification effected for various hydraulic loadings, algal production, depth, detention time, visible radiation etc., and from these data rational criteria as design parameters have been determined for the single cell unit. In the second paper the author has dealt with the development of a pink colour in the two types of oxidation ponds. The pink colour has been traced to the presence of a member of the Thiorhodaceae group of organisms — a purple coloured sulphur bacterium in the pond. The conditions under which this organism develops in the ponds, its physiology and its role in the purification of sewage and its association with certain algal forms are discussed.

****

I. INTRODUCTION

In the Report on Seminar (1955) held at Kandy in Ceylon on Sewage Disposal (Rural & Urban) by the W.H.O. for South-East Asia, it is stated that although sewage lagoons have been used in several western countries as a satisfactory technique for treating sewage, as yet, it has not been deliberately applied in any country of Asian origin. Since then, it is gratifying to record that attempts have been made at Nagpur (Modak 1960), (Others 1961) to purify sewage by the oxidation pond method from which it was concluded that a loading of 500 lbs per acre per day could be easily applied to get a reduction of 72% in B.O.D. with a retention period of two days. Lakshminarayana et al (1963) continuing the above experiments at Nagpur studided the relation between detention time and B.O.D. removal, and stated that with an average loading ranging from 320 to 800 lbs. per acre per day a higher degree of purification was possible at five feet operational depth with 4 days, 2 days and 1.5 days detention periods. Parhad and Rao (1963) have stated that mechanical aeration has little effect on bacterial reduction which amounted to 81 to 98.6%; that various groups of bacteria were responsible for stabilization, some of which were perhaps more active than coliforms and entero-cocci; and that intestinal pathogens belonging to <u>Salmonella</u> and Shigella groups seemed to be eliminated. Jagannatha Rao

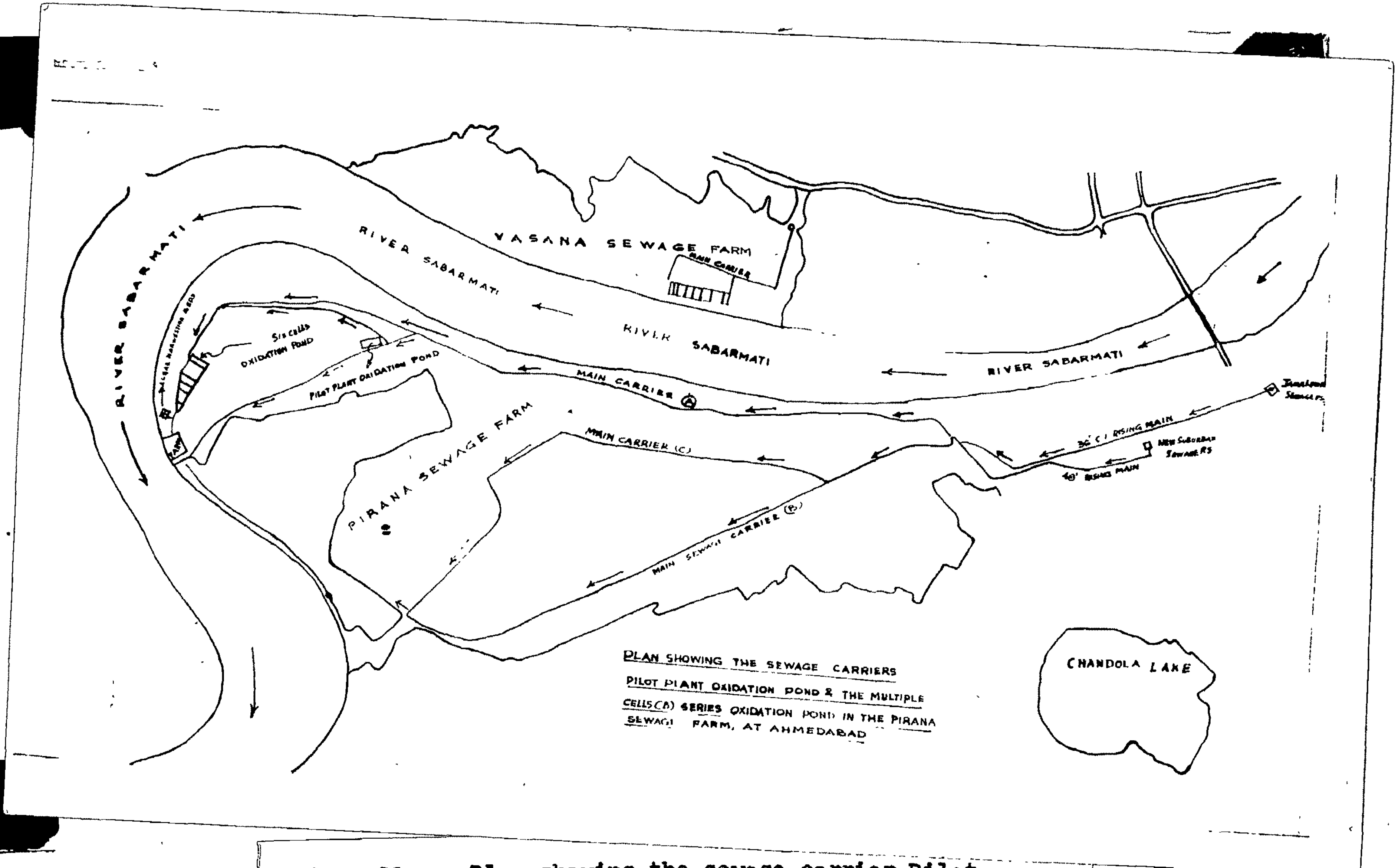


Fig. 26. Plan showing the sewage carrier Pilot-plant oxidation pond and the multiple cell series of oxidation ponds in the Pirana Sewage Farm.

and Sharma (1963) treated the domestic sewage of Bhopal by this process and obtained a B.O.D. reduction varying from 35 to 50% only, but a coli count reduction of about 99%. Basu (1963) obtained a 5-day B.O.D. reduction of 78% in a 7 acre pond having a depth of 3 to 3.5' with an influent 5-day B.O.D. at 20° C. of about 230 ppm. Murty et al (1963) carried out pilot-plant experiments with the sewage of Hyderabad and obtained a B.O.D. reduction of nearly 70%. Khanade (1963) who estimated the quantity of amino-acids in the oxidation ponds of Ahmedabad found that the domestic sewage contained more than the mixed sewage (containing domestic sewage to textile wastes in the proportion of 3 : 1); and that there was a significant reduction in both forms of amino-acids in the effluents from oxidation ponds. Ganapati et al (1965) have studied the ecology of solar sewage drying beds in the Pirana sewage farm at Ahmedabad and have concluded that the solar drying beds resembled the type II oxidation pond of Oswald and Gotaas (1957) in their smaller size with a detention period of one week where stabilization of sewage was brought about essentially by photo-physiological action of certain species of blue-green planktonic algae in conjunction with bacteria.

None of these Indian workers had attempted to furnish the ecology and seasonal succession of algae extending over several years. Even in the West much information has been furnished only for criteria on rational designing. For example, Oswald and Gotaas (1957) and Gotaas and Oswald (1955) have developed design criteria for oxidation ponds taking into account both the controllable and non-controllable factors in the operation of stabilization ponds. Duttweiler (1963) has proposed " a simplified mathematical model based on an assumed upper layer of complete mixing where temperature is isotropic and a lower layer where heating is by vertical eddy conduction alone. The model required testing and verification". Suwannakaran and Gloyna (1963) have evaluated under laboratory conditions the effects of temperature and organic loading on the performance of waste stabilization ponds with a view to establish better design criteria. They found that within limits the B.O.D. removal increased with the increase of temperature; changes in biological activity due to temperature fluctuations influenced the pH, MPN of coliforms, suspended solids, light transmission, predominant algal species, and the required pond volume and that excessively long detention periods did not result in better B.O.D. reductions. They claimed that it was possible to formulate a design equation taking into account both temperature and pond loading. Van R. Marais (1962) has presented a rational theory for the design of sewage stabilization pond in tropical and sub-tropical areas of Africa based on the correlations of the kinetics of B.O.D. and faecal bacteria reductions in a series system of stabilization ponds.

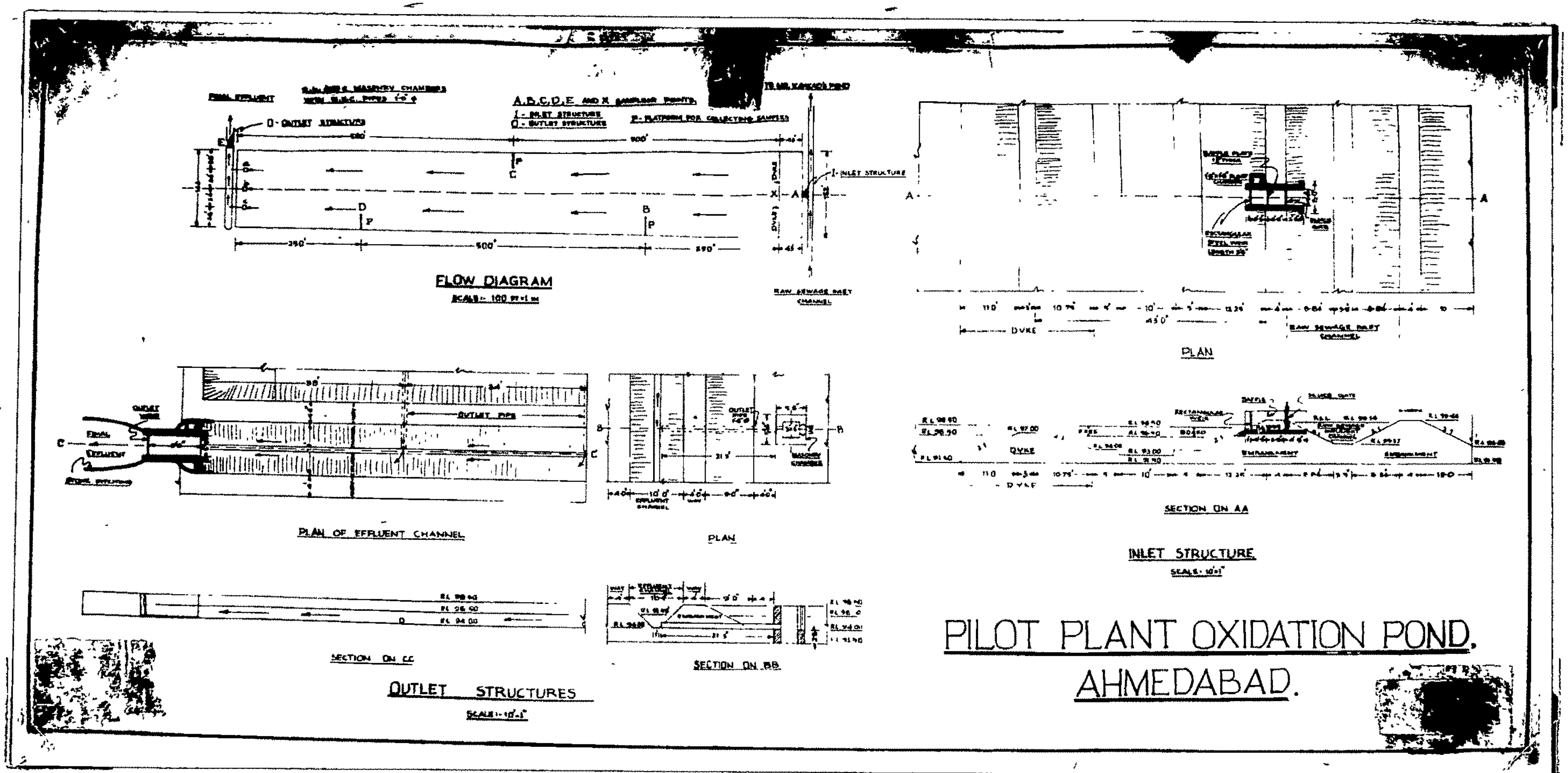


Fig. 27. Plan and section of the Pilot Plant Oxidation Pond in the Pirana Sewage Farm.

One of the most complete studies on oxidation ponds was carried out by the USPHS at Fayette, Mo., by Neel et al (1961). "Five identically sized oxidation ponds were loaded at 5-day B.O.D. loading rates of 20, 40, 60, 80 and 100 lbs/acre/day. These data showed that oxidation ponds were very efficient at B.O.D., phosphate and nitrogen reduction".

Parker (1962) has furnished data on eight oxidation ponds, working in series for a six week summer and winter periods. The first 2 ponds were anaerobic and the last six were aerobic. The BOD reduction was excellent throughout the ponds. Nitrogen removal was insignificant through the first 5 ponds but showed a definite reduction by the 8th pond. In winter also, they showed a satisfactory BOD reduction and confirmed poor nitrogen removals.

Bogan et al (1960) made a study on the removal of P by algae in an effort to remove this key nutrient from sewage effluents. It was found that P was removed primarily by chemical precipitation rather than biological metabolism.

Bush et al (1961) studied the use of algae as a tertiary treatment device for removing minerals from an activated sludge effluent. Natural gas was burned to furnish a continuous source of CO_2 for algal growth and to maintain a pH between 7.0 and 8.5. There was a maximum removal of 38 38% Ca, 44% Mg, 90% removal of HCO_3 ,41% of sulphate, 76% of phosphates and 100% N. The algae grew on the sides of the treatment unit.

There are only a few references: Myers (1948), Silva and Papenfuss (1953), Allen (1955), Neel and Hopkins (1956) and Merz et al (1957), which deal mainly with the quantitative and qualitative growth studies of algae in sewage oxidation ponds. An attempt was therefore, made to develop design criteria and criteria for operation of oxidation ponds trapping the energy of the sun at Ahmedabad through photosynthesis as the principal synthetic source for purifying the sewage of Ahmedabad. The ecology and seasonal succession of algae developing in the oxidation ponds investigated were studied during the years 1962-1963 and the results of the same form the contents of the second main paper.

II. THE CITY OF AHMEDABAD

1. Location: The city of Ahmedabad is located at 23.01 North latitude at an elevation of 163 above the mean sea level. It has an area of 32.5 sq. miles. The city is divided into two parts by the river Sabarmati which runs from north to south.

2. Population: According to the latest census of 1960, its population was 11.34 lakhs of people, of which about 60,000 are living on the western side which is fast developing and the remaining on the eastern side of the river.

3. Climatological data: The data are shown in Table I (Appendix). The four seasons in Ahmedabad are the cold weather period constituting December, January and February, the hot weather period consisting of March to June, the Monsoon season of July, August and September and the post-monsoon season of October and November. The salient features of the four seasons of 1962 and 1963 are shown below:

TEMPERATURE (°C)

SEASON	AVERAGE				RANGE			
	1962		1963		1962		1963	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Cold weather	29.5	12.5	29.8	14.0	9.5	31.5	12.3	33.6
Hot weather	38.9	23.7	37.6	23.7	18.3	42.3	13.6	41.2
Monsoon season	32.9	25.0	31.2	24.1	24.0	33.5	21.6	33.0
Post-monsoon season	33.8	16.9	33.9	19.8	15.9	34.6	18.5	35.6

MONTHLY HOURS OF BRIGHT SUN-SHINE

SEASON	MONTHLY AVERAGE 1962	MONTHLY AVERAGE 1963	MONTHLY RANGE 1962	MONTHLY RANGE 1963
Cold weather	290.2	283.9	273.2-307.8	273.2-292.0
Hot weather	305.2	305.5	286.0-339.5	289.8-357.7
Monsoon	249.2	157.7	138.7-215.9	119.8-202.1
Post-monsoon	291.1	277.1	277.5-304.8	268.1-286.2

Ahmedabad has an average annual rainfall of about 30" only most of which occurring during the monsoon season. The maximum average temperature reached was 42.3^{o} C. in 1962 and 41.2 in 1963 in the hot weather and the minimum temperature reached was 12.3-12.5 in the cold weather. The total number of hours of bright sunshine varied from a minimum of 119.8-138.7 in August to a maximum of 339.5-357.7 hours in May. So, Ahmedabad may be considered to have a dry, sunny climate and a high rate of evaporation.

4. Water supply: The soil in and around the city is sandy extending to a depth of about 24 feet. A good yield of underground water, is therefore, available throughout the city. The City's water supply amounting to 46.5 mgd. is obtained from three sources. The main source is from 27 infiltration wells which have been sunk in the bed of the Sabarmati near Dudeshwar from which an average yield of 21 mgd. is obtained. About 9 mgd. of the surface river water are being treated in a Candy's Rapid filtration Plant, and the balance of 16.5 mgd. are being obtained from 30 deep bores and tube wells which are located in the suburbs of the city. So, nearly two-thirds of the city water supply is river water which is soft and a third is nearly medium hard. The calcium concentration in the water supply is expected to be low.

The characteristic quality of the two types of water supply is given below:

Sr. No.	Description	Bore well water(parts per milli-ons)	Dusheshwar raw river water(parts per milli -ons)
1.	Total solids	1438.0	315.0
2.	Volatile solids	150.0	30.0
3.	Suspended solids	210.0	0.20
4.	Dissolved solids	1219.0	314.8
5.	Chlorides	296.0	88.0
6.	Saline ammonia	0.050	0.02
7.	Albuminoid ammonia	0.040	0.01
8.	Nitrites	0.005	Nil
9.	Nitrates	4.2	2.2
10.	Oxygen consumed	1.2	0.40
11.	Total alkalinity	218.0	302.0
12.	pH	8.1	7.8

Fig. 28. Photograph showing the beginning of the sewage carrier in the Pirana Sewage Farm.

5. Sewarage system. Almost the entire city is sewered and the city sewage is ultimately received in three main pumping stations, two of which called the Jamalpur and the New Suburban are located on the eastern side and the Vasana on the western side of the river. The jamalpur pumping station receives domestic sewage of 18 mgd from a population of 5.11 lakhs of people and the New Suburban Pumping station gets 21 mgd. of domestic sewage from 5.63 lakhs of people and about 12 mgd. of textile mills wastes. The Vasana Pumping Station which is located on the western side of the river gets purely domestic sewage of about 6.0 mgd. from a population of about 0.6 lakhs of people.

6. Sewage disposal: The entire sewage of the city is disposed off by broad irrigation in two sewage farms. The oldest of the two called the Pirana Sewage Farm, is located on the eastern side of the river comprising 2856 acres of sandy soil on the river bank. The other sewage farm at Vasana is much less in area having about 50 acres in the sandy soil on the western river bank.

7. Industrial wastes: There are a number of industries which are located within the city limits. At present there are 64 textile mills, one dairy, several oil and seed pressing mills, a soap making industries, one saall tannery and one starch making factory. Of these, the wastes from 64 textile mills are the largest in quantity amounting to about 12 mgd.

At present the mill wastes are being purified by a common method of spraying them over gypsum blocks for reducing their sodium content after preliminary sedimentation of their suspended solids. The final effluent after secondary sedimentation is emptied into the nearby municipal sewer. The wastes from other industries are not treated but are allowed to go straight into the municipal sewer.

8. Character of the Sewage at the entrance to the Pirana Sewage Farm:

The sewage received at the three main pumping stations differ both in quality and quantity. The sewage that is received at the Vasana Pumping Station is entirely domestic in character; that from Jamalpur Pumping Station is also practically domestic, with wastes from one textile mill only and the New Suburban Pumping Station receives a fairly large amount of textile mill wastes from 63 textile mills and other industries in addition to domestic sewage.

The sewage from the two main pumping stations located on the eastern side of the river is pumpted to the oldest Pirana Sewage Farm, where the two sewages are mixed in a hopper shaped main open carrier or channel having a gradient of 1 in 1000; and the flow in it varies from 20 to 40 mgd., during the course of the day. The sewage is thus carried for a

Fig. 29. (a) Viens of the Sewage Carriers from the Jamalpur and New Suburban Sewage Pumping Station; and (b)of the main sewage carrier after mixture.

more than 5 miles in the open channel for irrigating 2849 acres of sandy soil. There are also a number of branch carriers which carry sewage for irrigating plots of land distantly located from the main channel. The ground level at the beginning of the channel is 101 RL and at the end of 5 miles about 60 RL.

The salient features of the sewage at the beginning and at the end of 5 miles of the carrier, are shown below:

Seasons	5 day BOD at 20 C			Oxygen consumed by acid $KMnO_4$ (4 hours)		
	Beginning	at the end of 5 miles	% Reduction	Beginning	at the end of 5 miles	% Reduction
Summer	316.6	108.0	66.0	73.8	38.4	48.0
Monsoon	218.1	130.7	40.1	65.0	43.9	32.3
Post-monsoon	288.6	141.8	50.8	61.9	41.4	33.1
Cold weather	334.5	157.8	52.9	69.5	37.6	45.9

It will be seen from the above that there is an average reduction of 60% and 49% in BOD and oxygen consumed tests respectively on account of travel over a distance of about 5 miles in the open carrier (or channel) in the Pirana Sewage Farm.

III. SINGLE CELL (PILOT PLANT) OXIDATION POND.

(i) Location: The Pilot Plant oxidation pond was constructed by the Ahmedabad Municipal Corporation in the interior of the Sewage Farm at a distance of about 5 miles from the entrance of the sewage into the Farm (Fig.2B) on the banks of the river Sabarmati. Therefore, the quality of sewage considerably improved as a result of travel in an open channel for 5 miles as stated above.

(ii) Engineering Design Data: The Pond is shown diagramatically in Fig. VI. It is divided into two compartments by a dyke of 3' in height. The side dykes or embankments were formed with excavated sand and raised to about 8' above the ground. Raw sewage (after travel over a distance of 5 miles) is admitted into the first compartment measuing 43' long and 125' broad through a rectangular weir, which regulates the flow of sewage into the first smaller pond from which the liquid over flows the dyke into the second bigger pond measuring 1000' long and 125' broad and 8½' high. It is thus a three acre pond with a holding capacity of 4 mgd.

Three 30' piers which project into the bigger pond are located at 250', 500' and 750' from the dyke for collection of samples. The final elluent is allowed to flow through three one-foot diameter Hume pipes into a channel

Fig. 30. Views of the Pilot plant oxidation pond in the Pirana sewage Farm.

running across the breadth of the pond and at one end of which another rectangular weir with a scale is provided for measuring the rate of out-flow from the bigger pond.

III. MATERIALS AND METHODS:

The sewage used in these experiments was the mixed sewage from the Jamalpur and New Suburban pumping Stations. The sewage had travelled over a distance of nearly 5 miles in an open channel or carrier before it was used in the experiments. The characteristic quality of sewage from the two Pumping stations has been described in another paper by Kothandaraman et al (1963). The degree of purification taking place in the open carrier for a distance of 5 miles has been studied by Ganapati and Bopardikar (1962). The reaction rate constant "K" for the Ahmedabad sewage has been found to be 0.074 at 20°C. (Thergaonkar 1963). The 'K' value for the domestic sewage in the States is stated as 0.1 at 20°C.

A measured quantity of sewage, say ½", 1", 1½", 2", 3" or 4" was allowed to flow over the weir into the pond for a definite period. The depth was actually measured every day at 250', 500', 750' and 1000' length of the pond and the average depth was recorded for each hydraulic loading. The theoritical detention time was later correctly calculated from the volume of sewage in the pond and the average rate of flow during the period. Every alternate day either at 11.00 a.m. or 3.00 p.m. grab samples were taken at the inlet, 250', 500', 750' and 1000' from the surface from each sample -ing station for physical, chemical bacteriological and biological tests.

Three sets of samples were taken in the following order. Samples for bacteriological examination were taken first from the surface, next for chemical and biological tests. Bacterioloigcal examination for Coliforms at 37° C, E. Coli Type I at 44° C, Faecal Streptococci at 45° C. and Citrate utilisers at 37°C. was done according to the British Technique (Bacteriological Examination of Water Supplies 1939). Citrate utilisers were estimated after 48 hours (Keller 1960). This medium is specific for the identification of the members of the Coliform group, which are non-faecal or usually non-faecal in origin - and which are capable of utilising an ammonium salt as the sole course of nitrogen and sodium citrate as the sole source of Carbon. All results are presented in Tables of figures usually refer to the Most Probable Number (MPN) of organisms per millilitire of original sample. Two separate samples-one for dissolved oxygen and the other for BOD were taken in narrow mouth glass-stoppered bottles of 250 ml capacity taking the usual precautions for excluding air bubbles. Tests to show the extent of carbonaceous oxidation such as BOD and "oxygen consumed"

(Tidy's 4 hours test) and the removal and oxidation of nitrogenous compounds such as ammoniacal nitrogen, nitrous and nitrate nitrogen were done according to the Standard Methods (1960). The usual tests for chlorides, phosphates, alkalinity were also done according to the Standard Methods (1960). Temperature, and colour as it appeared to the naked eye were recorded for the physical conditions. Biological test to show algal production was done by the centrifuguing 10 or 15 ml of the formalin added sample at 3000 r.p.m. for 10 minutes. The sediment thus collected was made up to a known smaller volume and numerical estimation of the algal constituents was made by the drop-sedimentation technique (Standard Methods 1960). The data collected under physico-chemical, bacteriological and biological conditions are presented as monthly averages in the appendix. A discussion of the salient features of each important factor is made in the body of the paper. All results are expressed in milligrams per litre or parts per million unless otherwise sated.

(iv) PHYSICAL CONDITIONS

Colour: The final effluent was greenish (pale or dark) on most of the occasions although it was reddish on a number of occasions. The influent sewage was always found to be brownish or black.

Temperature: (°C) The range of temperature varied between 24.4 and 33.1°C. for raw sewage and between 19.7 and 31.1°C. for the final effluent during the period of investigation. The two graphs for raw sewage and the final effluent run almost parallel, the minimum being reached in January '63 and the maximum in May '63 in both the cases.

Seasonal variations: The seasonal averages and the range of variations are shown below:

TABLE NO. 1

SEASON		AVERAGE		RANGE	
		Raw sewage	Final Effluent	Raw sewage	Final Effluent
Monsoon	1962	31.4	30.1	30.7-32.1	29.6-30.5
Post-monsoon	1962	30.2	25.7	31.0-29.4	25.3-26.1
Cold weather	1962-1963	25.9	22.7	24.4-27.4	19.7-24.4
Hot weather	1963	31.5	29.0	29.0-33.1	26.8-30.2
Monsoon	1963	31.3	29.7	31.1-31.7	28.9-31.1
Post-monsoon	1963	31.2	28.6	31.6-30.9	29.2-28.1

The highest and lowest averages were reached in the hot weather and cold weather periods respectively for raw sewage. For the final effluent the monsoon season of 1962 had the highest temperature and the cold weather period of 1962-63 the lowest temperature.

V. CHEMICAL CONDITIONS

(5-day B.O.D. at 20°C)

(a) MAXIMUM AND MINIMUM VALUES:

TABLE No. 2

Source	Maximum (ppm) Month	Value	Minimum Month	Value
Raw sewage	Aug. '62	292	Dec. '62	120
Final effluent	Feb. '63	90	Aug. / Sept. '63	29

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown below:

TABLE No. 3

S E A S O N		AVERAGE Raw sewage	Final effluent	% Red	RANGE Raw sewage	Final effluent
Monsoon	1962	255	67	73.7	230-292	52-88
Post-monsoon	1962	162	41	74.7	158-167	36-46
Cold weather	1962-63	175	56	68.0	120-208	33-90
Hot weather	1963	220	54	75.5	163-287	30-73
Monsoon	1963	169	34	81.0	160-178	29-45
Post-monsoon	1963	188	46	75.5	186-190	39-54

Maximum reduction in BOD was found in the monsoon season of 1963 and minimum in the cold weather of 1962-1963.

OXYGEN ABSORBED (4 Hrs.)

(a) MAXIMUM AND MINIMUM VALUES:

TABLE No. 4

SOURCE	MAXIMUM Month	MAXIMUM Value	MINIMUM Month	MINIMUM Value
Raw sewage	July '62	70	Sept.'63	26
Final effluent	Mar. '63	41	June '63	16

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown below:

TABLE NO. 5

S E A S O N		AVERAGE			RANGE	
		Raw sewage	Final effluent	% Red	Raw sewage	Final effluent
Monsoon	1962	60	36	40.0	53-70	33-41
Post-monsoon	1962	53	32	40.0	44-62	32-33
Cold weather	1962-63	46	37	20.0	30-60	28-40
Hot weather	1963	48	31	36.4	35-61	28-41
Monsoon	1963	38	28	26.3	26-49	31-32
Post-monsoon	1963	39	25	35.9	36-43	25

Maximum reduction in the oxygen absorbed test is recorded in the monsoon and post-monsoon seasons of 1962 and the minimum reduction in the monsoon season of 1963. The two curves for raw sewage and the final effluent seem to run almost parallel to each other.

DISSOLVED OXYGEN

(a) MAXIMUM AND MINIMUM VALUES:

TABLE No.6

SOURCE	MAXIMUM PPM Month	Value	MINIMUM Month	Value
Raw sewage	-	Nil	-	Nil
Final effluent	April'63	15.70	Sept.'62	1.71

(b) SEASONAL VARIATIONS: The seasonal averages and the seasonal range of variations are shown below:

TABLE NO.7

S E A S O N		AVERAGE		RANGE	
		Raw sewage	Final effluent	Raw sewage	Final effluent
Monsoon	1962	Nil	4.40	Nil	1.71- 4.00
Post-monsoon	1962	"	8.11	"	7.62- 8.60
Cold-weather	1962-63	"	3.80	"	2.00- 5.92
Hot weather	1963	"	9.86	"	3.15-15.70
Monsoon	1963	"	6.88	"	4.62-10.42
Post-monsoon	1963	"	6.19	"	5.66- 6.72

The dissolved oxygen content was found to be maximum in the hot weather of 1963 and minimum in the monsoon season of 1962 in the final effluent. There was no oxygen at any time in the raw sewage.

PERCENTAGE SATURATION OF OXYGEN

(a) MAXIMUM AND MINIMUM VALUES:

TABLE No. 8

SOURCE	MAXIMUM Month	MAXIMUM Value	MINIMUM Month	MINIMUM Value
Raw sewage	-	-	-	-
Final effluent	April '63	209.1	Sept.'62	22.6

(b) SEASONAL VARIATIONS:

TABLE No. 9

SEASON		AVERAGE Raw sewage	AVERAGE Final effluent	RANGE Raw sewage	RANGE Final effluent
Monsoon	1962	Nil	58.6	Nil	22.6-100.4
Post-monsoon	1962	"	113.0	"	110.3-115.7
Cold-weather	1962-63	"	40.0	"	22.7- 59.6
Hot weather	1963	"	138.8	"	64.0-209.1
Monsoon	1963	"	91.1	"	59.9-141.7
Post-monsoon	1963	"	82.9	"	77.3- 88.6

The pond was supersaturated with oxygen during the post-monsoon season of 1962; and the highest seasonal average was recorded in the hot weather of 1963 and the lowest in cold weather of 1962-63.

PHENOLPHTHALEIN ALKALINITY

(a) MAXIMUM AND MINIMUM VALUES:

TABLE No. 10

SOURCE	MAXIMUM PPM		MINIMUM	
	Month	Value	Month	Value
Raw sewage	Feb.'63	70	Sept.'63	Nil
Final effluent	May '63	112	Aug. '63	36

Raw sewage was alkaline to phenolphthalein almost throughout the period of investigation due probably to its admixture with textile mill wastes. The values for the final effluent were always higher than the corresponding values for raw sewage indicating that there was vigorous photosynthetic action in the pond.

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown below:

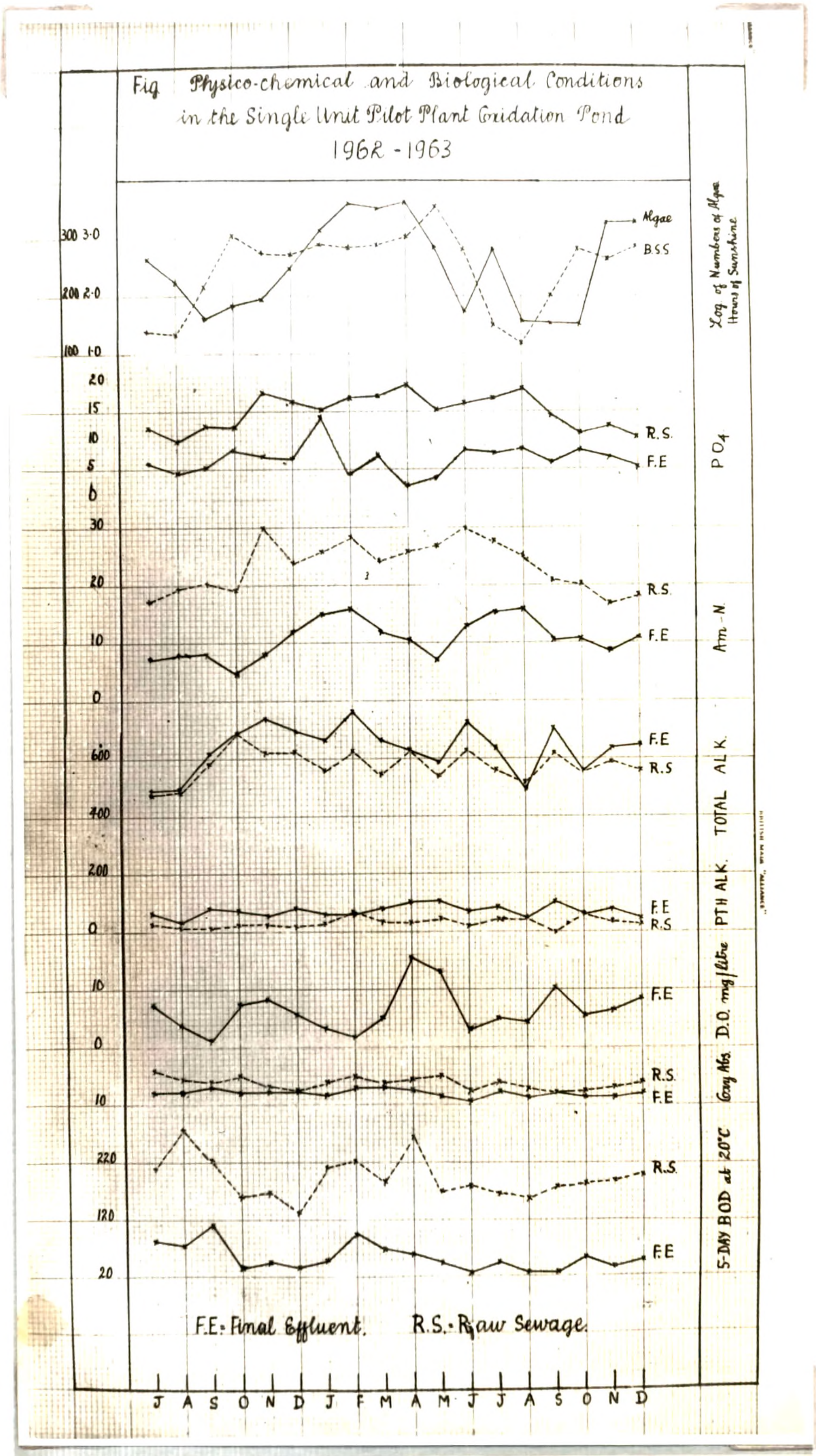


Fig. 31. Graph showing the physico-chemical and biological conditions in the Single unit Pilot Plant.

TABLE NO. 11

S E A S O N		AVERAGE Raw sewage	Final effluent	%. in-crea-se	RANGE Raw sewage	Final effluent
Monsoon	1962	25	63	152	20-34	36- 86
Post-monsoon	1962	29	69	138	28-31	59- 78
Cold-weather	1962-63	41	71	73.2	21-70	62- 84
Hot weather	1963	34	94	176.5	20-50	73-112
Monsoon	1963	32	63	97.0	Nil-48	49-87
Post-monsoon	1963	37	70	89.2	35-40	62- 79

The value for phenolphthalein alkalinity was highest during the hot weather of 1963 and lowest during the monsoon seasons of 1962 and 1963, showing different degrees of photosynthetic activity. The percentage increase was lowest in the cold weather of 1962-63 and highest in the hot weather of 1963. The two curves for raw sewage and the final effluent seem to run almost in opposite directions and the values for the final effluent were almost always greater than the corresponding values for raw sewage.

TOTAL ALKALINITY

(a) MAXIMUM AND MINIMUM VALUES:

TABLE NO. 12

SOURCE	MAXIMUM (PPM) Month	Value	MINIMUM Month	Value
Raw sewage	Oct. '62	689	July '62	483
Final effluent	Feb. '63	767	July '62	494

The values for total alkalinity for the final effluent were found to be higher than those of raw sewage:

(b) SEASONAL VARIATIONS: The seasonal average and the range of variations are shown below:

TABLE No. 13

SEASON		AVERAGE Raw sewage	Final effluent	% increase	RANGE Raw sewage	Final effluent
Monsoon	1962	521	539	3.4	483-595	494-622
Post-monsoon	1962	654	713	9.0	620-689	685-741
Cold-weather	1962-63	614	715	16.5	565-654	677-767
Hot weather	1963	593	661	11.5	558-636	599-733
Monsoon	1963	567	622	9.7	520-620	505-717
Post-monsoon	1963	578	601	4.0	562-594	566-636

A maximum increase of 16.5% and a minimum increase of 3.4% in the cold weather and monsoon season of 1962-63 were recorded. Generally the values for total alkalinity for the final effluent were greater than the corresponding values for raw sewage. The two curves for raw sewage and the final effluent seem to run almost parallel to each other.

CHLORIDES

(a) MAXIMUM AND MINIMUM VALUES:

TABLE NO. 14

S O U R C E	M A X I M U M (PPM)		M I N I M U M	
	Month	Value	Month	Value
Raw sewage	Jan. '63	385	July '62	262
Final effluent	April '63	472	June '63	201

Lowest values were recorded in June '63 and July '62 respectively for the final effluent and raw sewage and highest values in the cold weather and hot weather of 1963 for raw sewage and final effluent respectively.

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown in Table No.15.

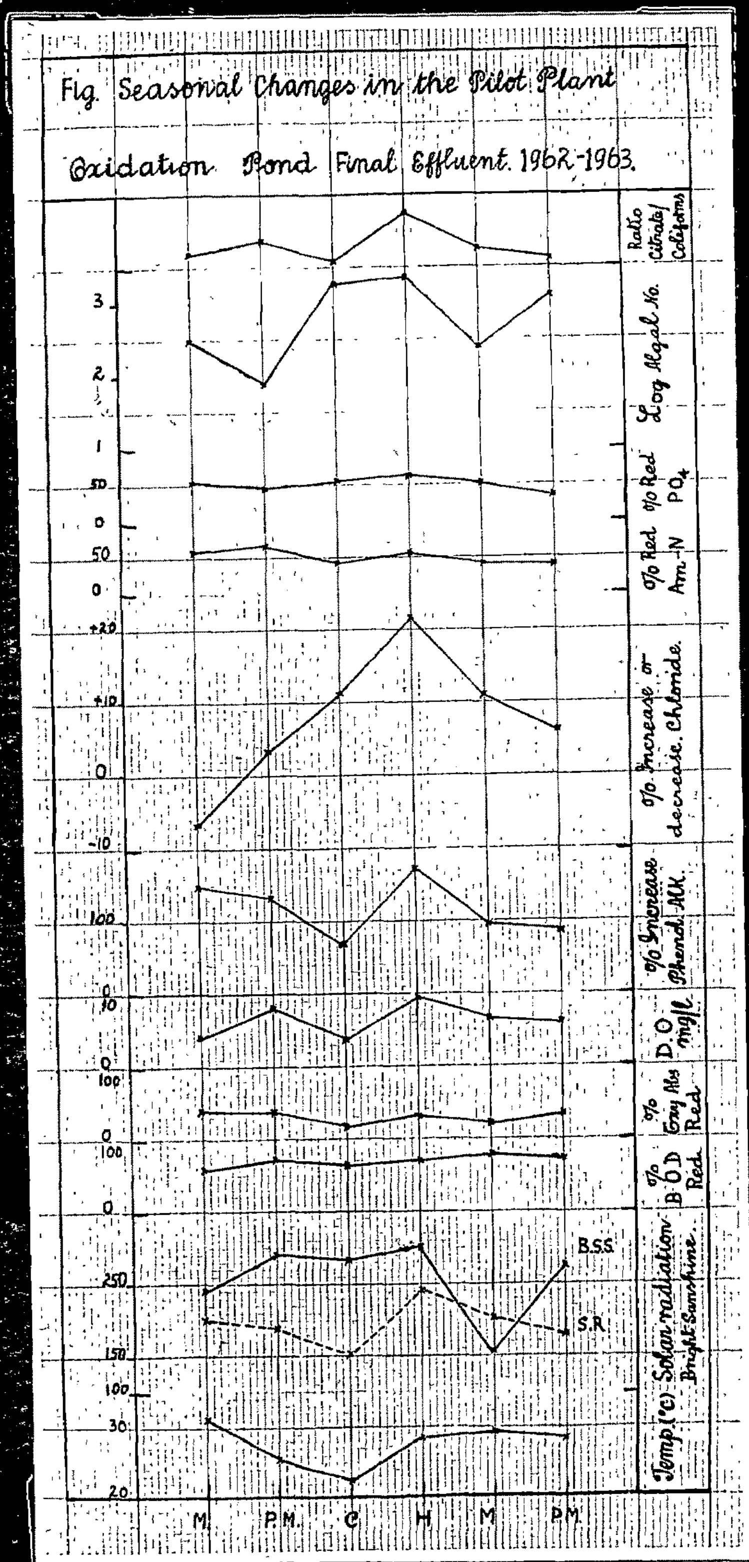


Fig. 32. Graph showing the seasonal changes in the important parameters of the Single unit.

TABLE NO. 15

SEASON		AVERAGE Raw sewage	AVERAGE Final effluent	%Reduction or increase + or -	RANGE Raw sewage	RANGE Final effluent
Monsoon	1962	292	272	- 6.5	262-333	258-288
Post-monsoon	1962	330	442	+ 34.0	320-341	441-434
Cold-weather	1962-63	360	400	+ 11.1	316-385	370-436
Hot-weather	1963	327	398	+ 21.7	310-360	201-472
Monsoon	1963	290	322	+ 11.0	260-320	278-356
Post-monsoon	1963	322	342	+ 6.2	292-353	284-400

For the raw sewage the highest average was recorded in the cold weather period and the lowest in the monsoon season of 1963; and for the final effluent the maximum was recorded in the post-monsoon season and the minimum in the monsoon season of 1962. There was a reduction in the value for chlorides in the final effluent in the monsoon season of 1962 and in the remaining periods it was higher than the corresponding values for raw sewage due probably to concentrations. Fitzgerald and Roechlich (1958) have also stated that variations in chloride were not consistent. The values increased sometimes and decreased at other times for which no satisfactory explanation can be offered.

AMMONIACAL NITROGEN

(a) MAXIMUM AND MINIMUM VALUES:

TABLE NO. 16

SOURCE	MAXIMUM (PPM) Month	Value	MINIMUM Month	Value
Raw sewage	June'63	30.0	Nov.'63	17.0
Final effluent	Feb.'63 Aug.'63	16.0	Oct.'63	4.8

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown below:

TABLE NO. 17

SEASON		AVERAGE Raw sewage	Final effluent	% Red	RANGE Raw sewage	Final effluent
Monsoon	1962	19.3	7.9	59.0	17.5-20.5	7.7-8.0
Post-monsoon	1962	24.7	6.5	73.6	19.4-30.0	4.8-8.2
Cold weather	1962-63	26.3	14.4	45.3	24.1-28.8	12.1-16.2
Hot weather	1963	21.9	10.8	59.8	14.6-30.0	7.1-13.0
Monsoon	1963	24.9	14.1	43.4	21.0-28.0	6.4-8.9
Post-monsoon	1963	18.8	9.5	40.0	17.0-20.6	7.2-8.3

Maximum and minimum reduction were recorded in the post monsoon seasons of 1962 and 1963 respectively.

PHOSPHATES (PO4)

(a) MAXIMUM AND MINIMUM VALUES

TABLE NO. 18

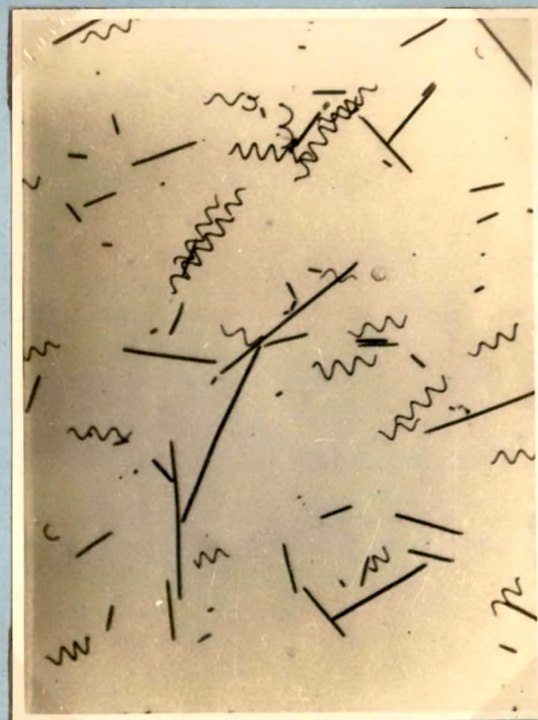
SOURCE	MAXIMUM (PPM) Month	Value	MINIMUM Month	Value
Raw sewage	Aug.'63	19.0	Aug.'62	10.0
Final effluent	Jan.'63	9.2	April '63	2.5

(b) SEASONAL VARIATIONS: The seasonal averages and the range of variations are shown below:

TABLE NO. 19

SEASON		AVERAGE Raw sewage	Final effluent	% Red.	RANGE Raw sewage	Final effluent
Monsoon	1962	11.8	5.5	53.4	10.0-12.9	4.5-6.2
Post-monsoon	1962	15.5	8.1	47.7	12.5-18.6	7.6-8.6
Cold weather	1962-63	16.6	7.1	57.2	15.4-17.4	4.7-9.2
Hot weather	1963	15.0	5.7	62.0	12.9-16.8	2.5-8.7
Monsoon	1963	17.1	7.8	54.4	18.8-19.0	6.4-8.9
Post-monsoon	1963	12.0	7.7	36.0	11.4-12.6	7.2-8.3

Fig. 33. Photo-micrographs of (a) Pandorina,(b) mixture of Oscillatoria and Arthrospora & (c) Ankistrodesmus in the Single unit.



Phosphate reduction was greatest in the hot weather and lowest in the post-monsoon season of 1963.

(VI) BIOLOGICAL CONDITIONS

The list of algal and other organisms recorded during the period of investigation is given below:

TABLE NO. 20

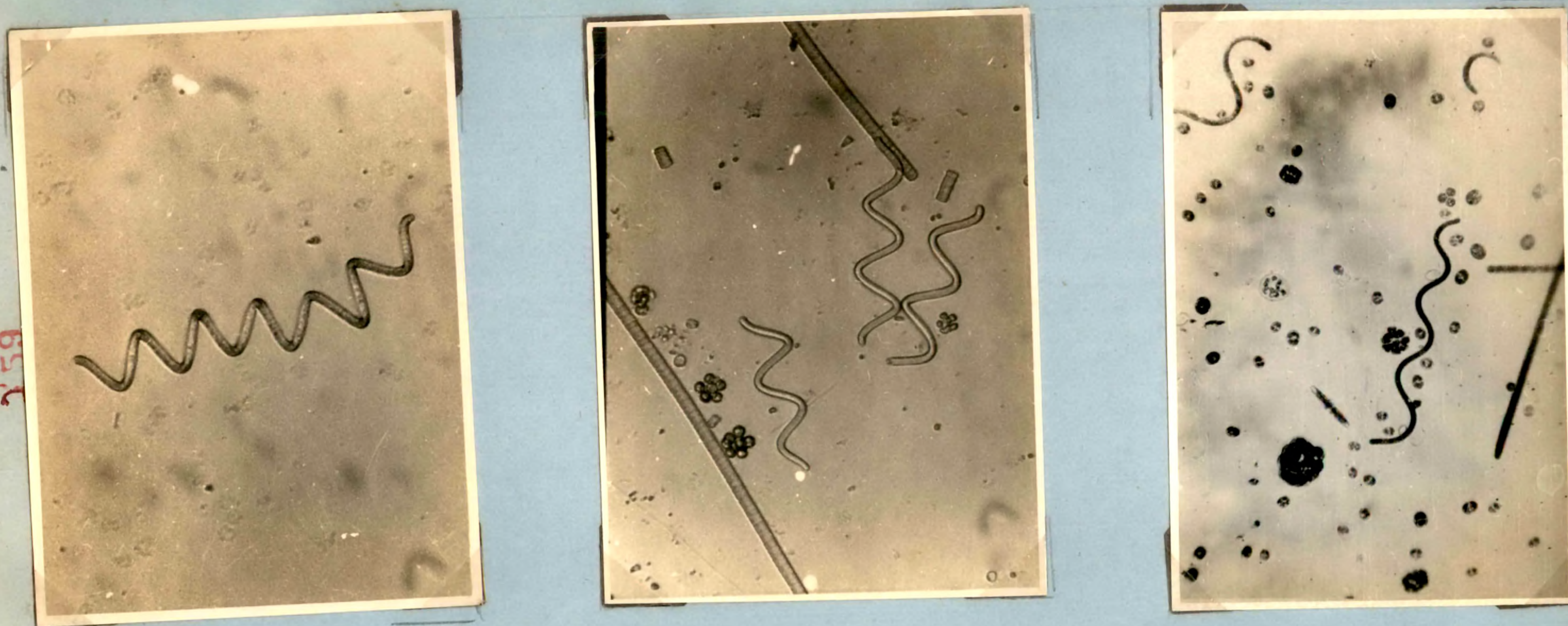
A. CHLOROPHYTA

1. Ankistrodesmus falcatus (Corda) Ralfs.
2. Chlamydomonas Sp.
3. Chlorella pyrenoidosa Emerson
4. Crucigenia sp.
5. Chlorococcum humicola Nag.
6. Cosmarium sp.
7. Micractinium pussilium Fres.
8. Oocystis lacustris chodat.
9. Palmella sp.
10. Pandorina morum Bory.
11. Pyrobotrys gracilis Korshikov.
12. Scenedesmus armatus Chodat.

B. EUGLENOPHYTA

13. Euglena gracilis

Fig. 34. Photo-micrographs of (a) Arthrospira enlarged



C. CYANOPHYTA

14. Arthrospira Khannae Dr. & Strickl.
15. Chroococcus turgidus (Kutz) Nag.
16. Microcystis aeruginosa Kutz.
17. Oscillatoria chalybea (Mertens) Gom.
18. Oscillatoria limosa Ag.

D. DIATOMS

19. Nitzchia palea
20. Navicula sp.

E. THIORHODACEAE

21. Thiopedia rosea Winogradsky.

GENERAL GROUPING OF THE ORGANISMS ACCORDING to THEIR QUANTITY:

The total number of organisms recorded for the pond may be broadly classified under three groups: Group I, constituting the dominance in any month; Group II, constituting sub-dominance in any month and group III including those organisms which were comparatively rare:

TABLE NO. 21

(DOMINANT ORGANISMS)

GROUP I

Chlorella pyrenoidosa

Micractinium pussilum Fres

Chlorococcum humicola Naz.

Arthrospira khannae Dr. & Stdckl.

Thiopedia rosea Winogradsky.

(SUB-DOMINANT ORGANISMS)

GROUP II

Ankistrodesmus falcatus Ralfs.

Chlamydomonas sp.

Chroococcus turgidus

Micractinium pussilium Fres

Chlorella pyrenoidosa

Oscillatoria chalybea (Mertens) Gom.

Oscillatoria limosa Ag.

Euglena gracilis

Arthrospira khannae Dr. & Strickl.

Thiopedia rosea Winogradsky.

GROUP III

The rest of the organisms as recorded in Table 20.

The seasonal averages and the range of variations in the total number of organisms recorded per ml in the final effluent are given below:

SEASON		AVERAGE (per ml x 10^3) Final Effluent	RANGE
Monsoon	1962	341.3	171-452
Post-monsoon	1962	80.0	69- 91
Cold weather	1962-63	1922.0	307-3981
Hot weather	1963	2281.0	56-4724
Monsoon	1963	257.0	34-699
Post-monsoon	1963	1018.5	32-2005

Maximum number was recorded in the hot weather period and minimum in the post-monsoon season of 1962.

Seasonal succession of the dominant and the sub-dominant algae and other organisms.

The periodicity of the most dominant and sub-dominant organisms are shown in Table No.4 (Appendix) from which the seasonal variations of the organisms are shown below:

SEASON		Name of the Organisms	Percentage Dominant	Percentage Sub-dominant
Monsoon	1962	Chlorella	74.0-90.0	-
		Thiopedia rosea	-	4.0-18.6
		Ankistrodesmus	-	1.0
Post-monsoon	1962	Micractinium	81.3	4.3
		Thiopedia rosea	62.2	9.1
		Chlamydomonas	-	20.9
		Chroococcus	-	10.3
Cold-weather	1962-63	Chlorella	64.5	-
		Thiopedia rosea	-	21.9-31.8
		Chlorococcum	60.1	-
		Micractinium	-	7.7
Hot-weather	1963	Chlorococcum	60.9	-
		Thiopedia rosea	53.7-62.4	22.5-23.6
		Chlorella	64.7	35.1
		Micractinium	55.0	-
		Arthrospira	67.0	31.4
		Oscillatoria	-	23.7-23.9
		Euglena	-	21.0
		Chlamydomonas	-	13.0
Monsoon	1963	Thiopedia rosea	62.4-80.9	-
		Arthrospira	73.5-83.1	-
		Chlorella	-	20.2-20.6
		Oscillatoria	-	11.8-12.1
Post-monsoon	1963	Arthrospira	77.8	-
		Thiopedia rosea	90.0	22.4-23.6
		Chlorella	62.2	-

SEASON	Name of the Organisms	Percentage Dominant	Sub-dominant
	Micractinium	77.9	9.9
	Euglena	-	9.9
	Oscillatoria	-	13.6

It will be seen from the above that the purple coloured sulphur bacterium - Thiopedia rosea has been found to occur in all the seasons either as a dominant or sub-dominant organism. More about the role of this organism in purification of sewage has been discussed in the last paper of this thesis. Seasonal variations in species and numbers in oxidation ponds have been reported by Gotaas and Oswald (1955), Meffert (1955), Neel and Hopkins (1956) and Silva and Papenfuss (1953) and our studies confirm their findings.

Chlorella pyrenoidosa was the most dominant algal species in the monsoon season of 1962 and it was succeeded by Micractinium pusillum in the post-monsoon season. The latter was again succeeded by Chlorella pyrenoidosa and Chlorococcum humicola in the cold weather of 1962-63. Chlorococcum continued to be dominant for sometime and was later succeeded in turn by Chlorella, Micractinium and Arthrospira in the hot weather period of 1963. In the succeeding monsoon season Arthrospira continued to be dominant until it was succeeded by Chlorella again and then by Micractinium in the post-monsoon season of 1963.

Allen (1955) considered that in general the most numerous algae in oxidation ponds would species of Chlorella, Scenedesmus, and Euglena. "Chlorella was never a dominant in California lagoons studied by Allen" (Neel and Hopkins 1956). In our pond Chlorella was one of the dominating alga and it was found at all seasons.

Composition of the Bacterial Population:

The composition of the bacterial population of raw sewage and the final effluent is shown in Table No. 5 (Appendix) from which the following tabular statements have been prepared.

(a) MAXIMUM AND MINIMUM VALUES.

TABLE NO.23

Source	Maximum Month	Maximum Value	Minimum Month	Minimum Value
	COLIFORMS (MPN per ml)			
Raw sewage	April'63	88×10^4	Aug. '62	12×10^3
Final effluent	Feb. '63	940	Dec. '62	10
	E.Coli (Type-I) (MPN per ml.)			
Raw sewage	April'63	81×10^4	Aug. '62	90x10
Final effluent	Feb. '63	510	May '62	4
	FAECAL Streptococci (MPN per ml.)			
Raw sewage	July '62	29x10	Nov. '62	2.6
Final effluent	July '62	3.4	Dec. '63	0.026

CITRATE Utilisers

(MPN per ml.)

Raw sewage	Decm. '63	$46x10^5$	Sept.'62	$15x10^2$
Final effluent	March '63	1700	Sept.'62	14

Seasonal averages and the range of variations in respect of Coliforms, E. Coli Type I, Faecal Streptococii and Citrate utilisers are shown below:

TABLE NO. 24

COLIFORM FLORA (MPN per ml)

SEASON		Raw sewage (AVERAGE)	Final effluent (AVERAGE)	RED. %	Raw sewage (RANGE)	Final effluent (RANGE)
Monsoon	1962	$59x10^3$	73	99.9	$12x10^3$-$15x10^4$	14-80
Post-monsoon	1962	$68.5x10^3$	94.5	99.9	$45x10^3$-$92x10^3$	18-59
Cold weather	1962-63	8666	473	94.5	$40x10^3$-$16x10^4$	10-940
Hot weather	1963	397750	81	99.9	$43x10^3$-$88x10^4$	11-75
Monsoon	1963	25.7x10	117	99.9	$20x10^4$-$32x10^4$	24-250
Post-monsoon	1963	30.5x10	127	99.9	15x10-46x10	14-240

Maximum reduction of 99.9% in Coliform was recorded in all seasons excepting the cold-weather period of 1962-63 when it was slightly less(94.5%). Comparing the absolute values for the final effluent, it is found that the value is lowest in the hot weather of 1963 and highest in the cold weather period of 1962-63.

E. COLI TYPE I (MPN per ml.)

TABLE NO. 25

SEASON		AVERAGE Raw sewage	AVERAGE Final effluent	% RED.	RANGE Raw sewage	RANGE Final effluent
Monsoon	1962	191×10^2	17	99.9	$90 \times 10 - 54 \times 10^3$	16 - 73
Post-monsoon	1962	20150	16.5	99.9	$53 \times 10^2 - 35 \times 10^3$	15 - 18
Cold weather	1962 -63	30.7×10^3	253	99.1	$24 \times 10^3 - 43 \times 10^3$	110 -510
Hot weather	1963	284025	50	99.9	$91 \times 10^2 - 81 \times 10^4$	35 - 61
Monsoon	1963	14×10^4	52	99.9	$11 \times 10^4 - 17 \times 10^4$	21 - 99
Post-monsoon	1963	1355x10	119	99.9	31x10-24x10	74 -230

Maximum reduction has been recorded in all the seasons excepting the cold weather period of 1962-63 when it was only 99.1%. Comparing the absolute values for the final effluent it is found that the value is lowest in the hot weather and highest in the cold weather period of 1962-63.

FAECAL STREPTOCOCCI (MPN per ml.)

TABLE NO. 26

SEASON	AVERAGE Raw sewage	AVERAGE Final effluent	% Red	RANGE Raw sewage	RANGE Final effluent
Monsoon 1962	1014	1.6	99.8	50-29x10	.37-3.4
Post-monsoon 1962	4.9	0.39	92.0	2.6-7.2	.13-.65
Cold weather 1962-63	59.0	1.07	98.1	2.9-92	.40-2.30
Hot weather 1963	191	1.34	99.3	7.3-430	.03-2.10
Monsoon 1963	513	0.28	99.9	120-710	0.12-1.34
Post-monsoon 1963	39	0.03	99.9	15- 62	.03-.04

Maximum reduction is recorded during the monsoon and post-monsoon seasons of 1963 and minimum reduction in the post-monsoon season of 1962. The absolute values for the final effluent are very low in all the seasons.

CITRATE UTILISERS (MPN per ml.)

The seasonal averages and the range of variations are shown below:

TABLE NO. 27

SEASON	AVERAGE Raw sewage	AVERAGE Final efflu-ent	% Red.	RANGE Raw sewage	RANGE Final effluent
Monsoon 1962	3950	44	98.8	15×10^2-64×10^2	114 - 174
Post-monsoon 1962	9050	350	96.1	61×10^2-12×10^3	110 - 590
Cold weather 1962-63	30.3×10^4	487	98.4	19×10^3-46×10^3	120 - 910
Hot weather 1963	23.4×10^4	594	99.7	43×10^3-60×10^4	58- 1700
Monsoon 1963	32333	300	99.0	61×10^3-59×10^4	250 - 330
Post-monsoon 1963	18.5×10^5	154	99.9	13×10^5-24×10^5	68 - 240

Maximum reduction(99.9%) is recorded in the post-monsoon season of 1963 and minimum reduction (96.1%) in the post-monsoon season of 1963. The absolute values for citrate utiliseers in the final effluent were comparatively greater than the corresponding values for Coliforms or E. Coli Type I or Faecal streptococci.

Keller (1960) in his studies on the bacteriological aspects of pollution in the Jukskei-crocodile river system in the Transvaal, South Africa has recorded similar results. He considers E. Coli Type I test as practically the most sensitive index of pollution. Usually the results for E. Coli and Enterococci are in good agreement; the ratio between the groups is fairly constant, which is usually above 1; and that is so in our case also.

He has used Koser's citrate medium along with the other tests for the coliform group. He adds " Theoritically the number of Citrate utilisers and that for E. Coli should add up to the number of organisms belonging to the Coliform group, considering that Koser's citrate medium is of similar specificity for Aerobacter aerogenes, as MacConkey broth for E. Coli Type I. In fact this simple addition does not work out; MacConkey broth may show the presence of Coliforms of certain intermediate group, and citrate definitely shows the presence of certain pigment producing organisms, probably Pseudomonas and Chromobacter spp., both of which are, however, not of faecal origin and in the author's opinion, do not detract from the value of the determination".

" Again, Koser's citrate medium is not exclusively specific for non.faecal coliforms. Some non-faecal forms of the Coliform group, e.g., E. Coli Type II and the irregular strains, are incapable of using citrate, whereas a large number of bacteria which are not Coliform at all, do utilise citrates. This latter group includes Pseudomonas and Chromobacter Spp., genera which are usually abundantly represented in soil, vegetation, and natural waters, and which may therefore, be expected to have a substantial effect on the results where MPN procedures are employed" (Keeler 1960).

In the subjoined table the ratio between Coliforms and Citrate utilisers for the seasons is shown.

TABLE NO. 28

SEASON (MPN/ml.)		A V E R A G E		
		Coliforms	Citrate utilisers	Ratio: Citrate/Coliform
Monsoon	1962	73.0	144	2.0
Post-monsoon	1962	94.5	350	3.7
Cold weather	1962-63	473	487	1.0
Hot weather	1963	81	594	7.4
Monsoon	1963	117	300	2.6
Post-monsoon	1963	127	154	1.2

The citrate utilisers were about 1.0 to 7.4 times as numerous as the Coliforms in the final effluent suggesting that the majority of the organisms were not coliforms at all, but probably Pseudomonas and Chromobacter spp.(Keller 1960). The ratios also seem to show that non-faecal organisms were comparatively more numerous than the faecal organisms in the final effluent. Neel and Hopkins (1956), Neel et al (1961), Parker et al (1950), Towne et al (1957) have examined the bactericidal effect of various waste water treatment systems on coliforms. They found complete reduction of the Salmonella group along with 99.9% reduction in Coliforms.

Many theories and mechanisms have been suggested for the bacterial reduction such as (i) the production of materials toxic to bacteria, (ii) germicidal effect of sunlight, (iii) and competition for nutrients. Allen (1955), Oswald et al (1957) and Silva and Papenfuss (1953) state that the environment in the pond is antagonistic to coliforms. Others like Towne et al (1957), Smallhorst et al (1953) hold that extreme competition for the limited supply of nutrients is responsible for the destruction of coliforms. But this does not seem to be correct as only about 50% of the nutrients such as ammoniacal nitrogen and phosphates are used up.

Towne et al (1957), Caldwell (1946) and Pratt et al (1944) state that Chlorellin, an antibacterial substance liberated from Chlorella is responsible for the reduction.

Spoehr et al (1949) have determined the chemical nature of the antibiotic. They stated that Chlorella pyrenoidosa has been found to liberate fatty acids with a marked anti-bacterial activity. More work is necessary on the subject for other algal organisms than Chlorella have been also dominant during different seasons when there is also considerable reduction in Coliforms. The specific reason for the rapid destruction of coliforms in oxidation ponds is therefore, not yet clearly understood (Malina and Yousef 1964).

****

VIII DISCUSSION OF RESULTS

The pilot plant single unit oxidation pond was working satisfactorily for nearly two years and the inter-relationship existing between the algal organisms on the one hand and the physico-chemical and bacteriological conditions on the other are briefly discussed. The seasonal averages for the several factors are shown in Fig.31.

(a) Temperature, solar radiation and hours of bright sunshine:

The graphs for temperature and solar radiation are almost similar but the one for the number of hours of bright sunshine does not show any direct or indirect relationship with the other two graphs.

(b) Temperature and percentages of BOD and Oxygen consumed reduction.

No striking relationship seems to exist among the three graphs. But the graphs for the two latter factors seem to run almost parallel to one another indicating that the seasonal reductions are almost similar in the two cases.

(c) Temperature, solar radiation and the Citrate-Coliform ratio:

The three graphs run almost parallel to one another. The relationship appears to be more close between the solar radiation and the citrate-coliform ratio. The reduction in bacterial flora seems, therefore, to be dependent more upon solar radiation than temperature though the two latter are also intimately related.

(d) Temperature, solar radiation, hours of bright sunshine and algal numbers.

As regards algae generally the optimum temperature for their growth and developmant appears to be between 15°C. and 30°C; and that for most green algae the optimum temperature is 20°- 25°C. and for the blue-green algae still higher ranges of temperature. So, any temperature below these values can be expected to reduce the efficiency of oxidation ponds so far as nutrients removal is concerned (Fitzgerald and Rochlich 1958).

In the case of our pond, the temperature ranges during the different seasons do not show such striking differences as in Western countries. The temperature of the final effluent was found to vary between 19.7°and 31.1°C. and striking species differences in algae were therefore not noted. Both the green and blue-green forms were seen in all seasons.

The graphs for the temperature, solar radiation and the number of hours of bright sunshine do not also correlate with the graphs for the algal numbers. This is most probably due to the method adopted for the numerical estimation. One chlorella and one long filamentous Oscillatoria or Arthrospira cannot be expected to have the same amount of chlorophyll which is the factor involved in the photosynthetic oxygenation of the pond. But one minute Chlorella and a long filamentous Oscillatoria have been taken as single individuals in the numerical estimation and this method of counting has probably led to discrepancies noted in the algal graph. The more correct method to be adopted for comparison seems to be the estimation of chlorophyll content in the algal catch. But that was not done unfortunately.

(e) Phenolphthalein alkalinity, dissolved oxygen and algal density.

The first two factors show good relationship and they are intimately connected with algal growth and development in the pond. For, when algae multiply, they take away carbon dioxide from bicarbonates precipitating the more sparingly soluble carbonates which increase the phenolphthalein alkalinity and also add oxygen to the surrounding water during photosynthesis. Therefore, all the three factors should be closely connected.

But the graphs for the first two factors alone show direct relationship but not the one for algal numbers. Though greatest oxygen content is recorded in the hot weather when the hours of bright sunshine, solar radiation and algal numbers are also greatest, such a direct relationship is not traceable during the other seasons. The two graphs for algal numbers and oxygen production do not run parallel as one would expect. The relationship, therefore, indicates that the dissolved oxygen content estimated is not directly a measure of the quantity of molecular oxygen produced during photosynthesis but more likely, the resultant of the two opposing processes, namely, photo=synthesis and respiration going on in the pond (Neel and Hopkins 1956). Hence the two graphs do not seem to run parallel.

(f) Algal numbers and Percentage of BOD removal.

Algae produce oxygen required for bacterial oxidation during photosynthesis. The greater the algal numbers, the greater the oxygen production and the greater the bacterial oxidation and percentage of BOD removal. But the graphs for these two factors do not show the expected close direct correlation. The absence of any correlation between the two factors is most probably due to the non-estimation of the chlorophyll content. Towne et al (1957) and Neel and Hopkins (1956) have also stated that there was no tendency for the BOD removal to vary directly or indirectly with the plankton density during most seasons in their ponds.

(g) <u>Algal number and the limiting factors.</u>

Phosphates and nitrogenous substances are the two important nutrients used by algae for their metabolic processes. According to Fitzgerald and Roehlich (1958) ammoniacal nitrogen varying between 15 and 40 ppm is reduced to less than 2.0 ppm. In other words the reduction is more than 87 to 95%. He has given the quantity of the two nutrients removed from the oxidation ponds in various parts of the world during summer as follows:

LOCATION	AMMONIACAL		%	SOLUBLE -D		%Red.
	Inlet	Outlet	Red	Inlet	Outlet	
Calisloga, Calif.	3.4	0.9	73.5	-	-	-
Bergedorf, Germ.	25.3	2.3	90.9	-	-	-
Essen, "	15.0	2.0	86.6	-	-	-
Killen, Texas	14.0	0.5	96.4	-	-	-
Fuglebjerg, Denmark	16.0	6.0	62.5	-	-	-
Shoemaker, Calif.	15.0	1.0	93.3	-	-	-
Munich, Germ.	15.0	0.5	96.7	-	-	-
Melbourne, Austral.	32.0	16.0	50.0	-	-	-
Dortmud, Germ.	39.9	1.3	96.7	6.4	Trace	100
Moscow, U.S.S.R.	54.5	5.9	89.2	-	-	-

As regards phosphates, they have stated that a reduction of 96% is effected chiefly due to increased pH rather than due to utilization by algae. Unless the sewage originates from hard water containing excessive calcium content, the removal of phosphates is unlikely according to Bogan (1961). Caldwell (1946) stated that ammonia might disappear from the pond effluent in summer due to its utilization by bacteria and use by algae. Cooley and Jennings (1960) found an overall average reduction of 80% in ammonia in oxidation ponds.

Five identically sized oxidation ponds were loaded at 5-day BOD rates of 20, 40, 60, 80 and 100 lbs/acre/day. The data taken for Dec. 1957 and May 1958 in respect of ammoniacal nitrogen and orthophosphates by Neel et al (1961) are shown below:

December 1957		Raw sewage	Organic loading in Ponds 5day BOD 20	40	60	80	100
Phosphate	Mg/l.	38.6	3.8	5.2	7.2	5.9	6.9
Ammonia-N	"	46.5	5.0	5.8	3.4	5.1	6.0
May 1958							
Phosphate	"	31.3	5.9	5.5	9.4	12.0	14.3
Ammonia-N	"	26.0	4.8	5.5	7.7	12.2	12.9

Mckinney and Pfeffer (1965) state with reference to the above data as follows:

"The data of Neel et al (ii) do not agree with that obtained by the other investigators nor do they fit into the theoritical relationships as the other data do. The nitrogen and phospherous data indicate far greater removals than would be expected from such systems. Nitrogen is removed by the conversion of the inorganic nitrogen to organic nitrogen in cellular protoplasm and subsequent removal of the microbial protoplasm. Since microbial protoplasm was not mechanically removed from the system, the cellular mass must have settled to the bottom of the pond. Normally the settled microbial mass could have undergone endogenous metabolism with the release of the nutrient elements back into the liquid phase. While Parker's data (12) indicated that this reaction occurred, Neel's data (ii) did not. The phosphorous removal was in excess of that which could be accounted for by purely biological means; but this was probably accounted for by precipitation at the high pH values. The hard water of the Missouri area has a high calcium concentration and assisted in phosphate removal. Needless to say, such reductions would not have taken place in soft water regions where the calcium concentration in the waters would have been low".

In the case of our oxidation pond the range of reductions varied from 40.0% to 73.6% in ~~the~~ respect of ammoniacal nitrogen and 36.0% to 62.0% in respect of orthophosphates.

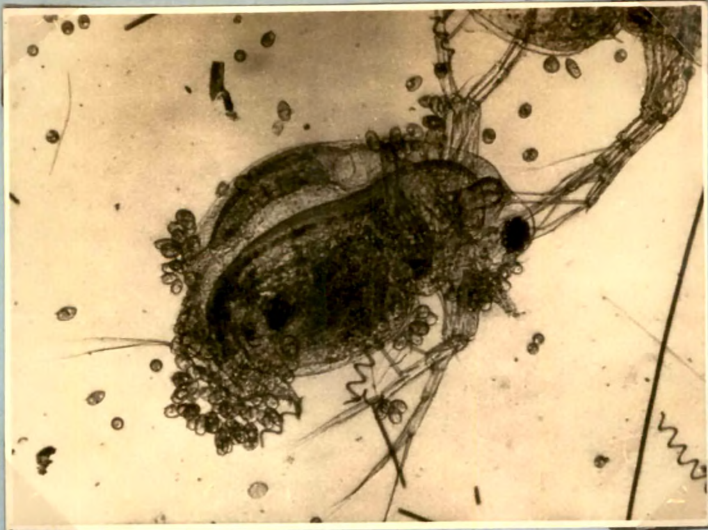


Fig. 35. Photo-micrographs of Daphmids in the Single unit.

These figures are not as excessive as those given above. Also, the water supply of Ahmedabad is the Sabarmati river water which is not hard. So, neither nitrogen nor phosphorous was a limiting factor for algal metabolism.

One striking feature of the graphs showing variations in seasonal averages is that the number of hours of bright sunshine, the percentage of BOD removal, percentage removal of oxygen absorbed, content of dissolved oxygen, percentage increase of phenolphthalein alkalinity, percentage increase of chloride, percentage increase of ammoniacal nitrogen and phosphate, logarithm of algal number and the ratio of citrate utilisers to coliforms are maximum or near maximum in the hot weather period of 1963.

(h) Problem of predatory Zoo-plankton.

Zoo-plankton organisms such as rotifers, cyclops, and cladocerans are known to eat away the algae in oxidation ponds thereby reducing their concentrations. Too long a detention period and shallow depth are reported to be helpful in this respect. In the Dakotas (U.S.D.H.E. & W; 1957), where the first pond was green and the second and third ponds were clear and colourless during summer and fall due to predatory organisms. They were found in these secondary ponds and consumed the algae and thereby removing the colour produced by the algae.

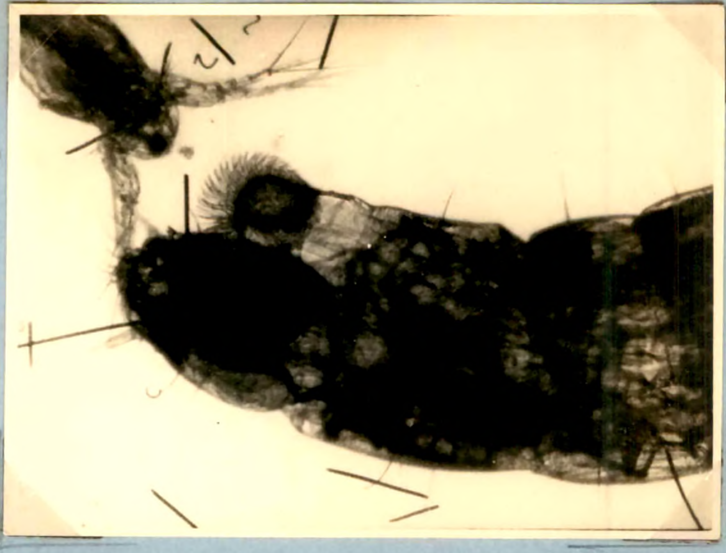


Fig. 36. Photo-micrographs of the two ends of a chironomous larva.

"Moina dubia", a daphnid was responsible for eating away all the algae-chlorella periodically in the single unit experimental oxidation pond at Nagpur (Krishnamoorthi 1965) and (Prabrahmam et al 1965). The organisms formed a bloom (40,000 per litre), when the temperature range was 28-30°C. and pH between 7.5 to 8.2. They seem to appear when the dissolved oxygen content was low and to die if the content is as high as 9.0 mg./litre.

Oswald (1964) has stated that algae predators such as rotifera and cladocera were occasionally observed during the early spring and summer when they consumed the disperse algal population; that most of the algae eaten by them were accumulated into faecal pellets which readily settled at the pond bottom investigated by him.

In the case of the pilot plant oxidation pond at Ahmedabad the same organism was found to occur in the final effluent imparting a reddish tinge only one one occasion along with Chironomid larvae. At the time of its appearance, the dominant algal organisms were Arthrospira khannae and Oscillatoria and the zoo-plankton could not eat away these filamentous forms and within a few days they disappeared. (Fig 35, 3b) Gummert et al (1953) have made similar observations. They found that chlorella cultures were more readily attacked by Protozoa than Scenedismus which showed a greater resistence.

So, it would appear that the zoo-plankton, organisms can eat away very small sized algal organisms like Chlorella and not filamentous forms like Arthrospira or Oscillatoria.

(i) Successive algal bloom in the Oxidation Pond.

It will be seen from a study of Table 3 that different algal organisms attain dominance in different months and sometimes, as for example in April and May 1963, more than one organism has been found to be dominant. Two Theories have been advanced. (i) According to Mckinney (1962) phytoflagellates like Euglena and Chlorella predominate in those areas where the nutrient level is quite high; and that the filamentous green algae appear " where the nutrient level drops off and the energy yield is not sufficient for large masses of the active phytoflagellate". So, " the over-all nutrient balance will determine exactly which forms will become dominant".

If this theory is applied to our pond, then, it is found that Chlorella is dominant in the months of July, August, September, December in 1962 and in January, April, November and December in 1963. Filamentous green algae were never found in our pond; but filamentous blue-green algae (Arthrospira) have been found in May, June, July, August, September and October in 1963.

If the values for BOD can be considered as an indicator of energy level, then the above organisms are found under the following conditions. The average BOD values when Chlorella is found to occur as a dominant organism is 64 mg./l. and only 33.5 mg./l. when Arthrospira is predominant.

M O N T H		DOMINANT Alga.	R.S.	F.E.
July	1962	Chlorella	211	87
August	1962	"	274	77
September	1962	"	227	113
December	1962	"	134	38
January	1963	"	212	51
April	1963	"	266	62
November	1963	"	190	39
December	1963	"	200	45
A v e r a g e			218.0	64.0
May	1963	Arthrospira	612	47
June	1963	"	183	27
July	1963	"	168	45
August	1963	"	160	29
September	1963	"	178	29
October	1963	"	186	54
A v e r a g e			173.0	38.5

Fogg (1960) has offered a different explanation for the predominance of the algal organisms in different seasons in a body of water. When an alga synthesises fresh cells it is very likely that a certain amount of organic substances formed within escapes into the surrounding medium according to Fogg (1953), a slight liberation of such substances from formed healthy cells of various species of Chlorophyceae but in growing cultures of species of blue green algae a good amount of the total organic matter synthesised regularly appears in a soluble form in the medium. These newly formed substances may be biologically active even in every low concentrations and according to Lucas (1947) their ecological effects may be considerable. They may be either growth promoting for other organisms (Krogh 1931) or inhibiting (Lefevre and Jakob 1949). Fogg and Westlake (1955) have shown that they may form chemical complexes with other dissolved substances. Aminoacids, polypeptides and proteins in general have a capacity for complex formation with other ionising substances. All blue-green algae have been found to liberate comparatively large amounts of organic nitrogen mostly in the form of poly-peptides (Watanabe 1951, Fogg 1952) and similar evidences have been obtained for other groups of algae.

Secondly, "if the phenomenon of extracellular enzyme production by algae is at all widespread these organisms must play quite a considerable part in the breakdown of organic matter in water. This is of interest in view of the growing use of algae in sewage disposal and deserves further investigation".

Thirdly, " other biologically potent substances released by algae may play an important role in determining what species are present in a given situation. It is tempting to explain the periodicity of phytoplankton observed in lakes and in the sea in terms of growth substances and antibiotics which, being released by one dominant species, determined the species which is to succeed it .... (Fogg 1960).

Fogg's explanation seems to be satisfactory but has to be confirmed by further experiments.

(ix) SUMMARY

1. In the single unit 4 mg pilot plant oxidation pond of Ahmedabad there was good algal production throughout the period of investigation. The dominant algae consisted of *Chlorella pyrenoidosa*, *Micractinium pussillum*, *Chlorecoccum humicola*, *Arthrospira khannae* and the sub-dominant algae were *Ankistrodesmus falcatus*, *Chlamydomonas* Sp., *Chroococcus turgidus*, *Oscillatoria limosa* and *Euglena* gracilis.

2. The algal constituents showed seasonal variations. The most dominant alga was Chlorella pyrenoidosa in the monsoon season of 1962; it was succeeded by Micractinium in the post-monsoon season. The latter was again succeeded by Chlorella and Chlorecoccum in the cold weather of 1962-63. Chlorecoccum continued to be dominant for some more time and was later succeeded in turn by Chlorella, Micractinium, and Arthrospira in the hot weather period of 1963. Arthrospira continued to be dominant in the succeding monsoon season, until it was replaced by Chlorella again, and then by Micractinium in the postmonsoon season.

3. Thiopedia rosea, a purple coloured sulphur bacterium was a constant form in the pond.

4. Maximum production of dissolved oxygen was 15.70 mg./l. in the hot weather period, when the percentage saturation was 209.1.

5. Maximum average reduction in BOD was 80% in the hot weather and the annual range was 61% to 80%.

6. Average reductions in nutrient substances of biological significance such as ammoniacal nitrogen and phosphates were 53.5% and 51.8% respectively.

7. 99.9% reduction in Coliforms was recorded. The ratio of citrate utilisers to coliforms was greater than 1.0 in all the seasons indicating that non-faecal organisms were comparatively more numerous than the faecal organisms in the final effluent.

****

(X) REFERENCES

1. Allen, M.B., Transactions of the Conference on the use of Solar Energy. The Scientific Basis Tucson, Arizona, 4, 27-37 (1955).

2. Bacteriological Examination of Water Supplies, Reports on Public Health and Medical Subjects No. 71., revised edition. HMSO, London, 59 pages (1939).

3. Basu, N.M., Symposium on Waste Treatment by Oxidation Ponds held at CPHERI, Nagpur, India, on October 29-30 (1963).

4. Bogan, H.H., O.E., Alberton and J.C.Pluntze., J. San. Engn. Div. Proc. ASCE. 86, SA. 5, 1-20 (1960).

5. Bush, A.F., J.D., Isherwood, and S. Rodgi., J. San. Engn. Div. Proc. ASCE, 87, SA. 3: 39-57 (1961).

6. Caldwell, D.H., Sewage Works J. 18, 433 (1946).

7. Duttweiler, D.W., Symposium on Waste Treatment by Oxidation Ponds held at CPHERI, Nagpur, India on October 29-30 (1963).

7a: Fitzgerald G.P. & G.A. Rohlich: Sewage industr. wastes. 30, 1213-1224 (1958)

8. Fogg, G.E., Proc. Roy. Soc. B. 139, 372-397 (1952).

9. Fogg, G.E., The Metabolism of Algae, Methnen, London (1953).

10. Fogg, G.E., Proc. Sym. on Algology, Indian Council of Agricultural Research 138-143 (1960).

11. Fogg, G.E., and D.F., Westlake. Verb. Int. Ver. Limnol. 12, 219-232 (1955).

12. Ganapati, S.V. and M.V. Bopardikar. J. Inst. Engrs. (India), 42, 672-688 (1962).

13. Ganapati, S.V., I.P.S. Prasada Rao, S.H. Godbole, V. Kothandaraman and Thomas Koshy. Hydrobiologia 26, 242-270 (1965).

14. Gillespie, C.G., Sewage Works J. 16, 740 (1944).

15. Gotaas, H.B., Oswald, W.H., and C.G. Golueke. 5th Progress Report. Inst. Engng. Research, University of California, Bull. Series 44,1 (1954).

16. Gotaas, H.B. and W.J. Oswald., Transactions of the Conference on the use of solar energy. The Scientific Basis, Tucson,Arizona Vol.4 Chapter 9, 95-114 (1955).

17. Gummert, F., M.E.Meffert, and H. Stratmann. Algal Culture from Laboratory to Pilot Plant. Edited by J.S.Burlow, Chapter 11, 174 (1953).

18. Jagannatha Rao, D.R., and T.P. Sharma. Symposium on Waste Treatment by Oxidation Ponds, held at CPHERI, Nagpur, India. October 29-30(1963).

19. Keller, P. Hydrobiologia 14, 205-254 (1960).

20. Khanade, J.M., Symposium on Waste Treatment by Oxidation Ponds, held at CPHERI, Nagpur, India on October 29-30 (1963).

21. Kothandaraman, V., V.P. Theragaonkar, Thomas Koshy and S.V. Ganapati. Environmental Health, 5, 356-363 (1963).

22. Kirshnamoorthi, K.P. Symposium on Crustacea-held under the Marine Biol. Assoc. India in the Oceanographic Laboratory, University of Kerala, Ernakulam, India on 12-15 January, 1965., p. 30 Abstracts.

23. Krogh, A., Biol. Rev. 6, 412-442 (1931).

24. Lakshminarayana, J.S.S., M. Parabrahmam, Khan, A.N., and D.Y. Ratnaparkhi. Symposium on Waste Treatment by Oxidation Ponds held at CPHERI, Nagpur, India, On October 29-30, (1963).

25. Lefevre, M. & Jakob, H.
C.R.Acad. Sci. Paris, 229, 234-236 (1949).

26. Lucas C. E.,
Biol. Rev. 22, 270-295 (1947).

27. Ludwig, H.F., Oswald, W.J., Gotaas, H.B., and V.Lynch.
Sewage & Ind. Wastes, 23, 1337 (1951).

28. Ludwig, H.F. and W.J. Oswald
Scientific Monthly 74,3 (1952).

29. Malina, J.F., (Jr.) & Y.A. Yousef.
J. Water Poll. Control. Fedr. 36, 1432-1442 (1964).

30. Marais van R.G.,
WHO Symposium on New Development in Sewage Treatment
Cincinnati (1962).

31. Mckinney, R.E.,
N.I.H.Progress Report, Project E 269(c) April 1,
1952 to May 1, 1953.

32. Mckinney, R.E.,
Biological Flocculation. Biological treatment of
Sewages and Industrial Wastes, N.Y.Reinhold, 1956
pp. 88-100.

33. Mckinney, R.E.,
Microbiologiy for Sanitary Engrs, Mcgraw-Hill Book
Co., 293 pages (1962).

34. Mckinney, R.E., & J.J. Pfeffe r.
Am J. Pub. Hlth., 55, 772-782 (1965).

34(a) Meffert M.E. Trans. of the conference on the use of solar energy. Vol IV, p 87-94 (1955)

35. Merz, R.C., J.C., Merrell & R., Stone.
Sew & Indr. Works. 29, 115-123 (1957).

36. Modak, N.V.
Report of the experimental work done on oxidation
ponds at Bazon Bagh. Nagpur, by CPHERI, 20-7-1960.

37. Moore, W.A., Smith, R.S., and C.C.Ruchhoft.
Sew. Works J. 21: 31-50 (1949).

38. Murthy, Y.S., G.K.Seth, K.R.Khan, & I.P.S. Prasad Rao.
Symposium on Waste Treatment by Oxidation Ponds,
held at CPHERI, Nagpur on October 29-30 (1963).

39. Myers, J.
Public Works, 79, 25 (1948).

40. Neel, J.K. & G.J. Hopkins,
Sewage & Indr. Wastes, 28, 1326-1356 (1956).

41. Neel, K.J.K., P.H.Dermott, C.E., Monday (Jr.)
J. Water Poll. Contr. Feder. 33, 603-641 (1961).

42. Oswald, W.J., Gotaas, H.B., Lundwig, H.F. & V. Lynch.
Sewage Indus. Wastes 25, 26 (1953).

43. Oswald, W.J., Gotaas, H.B. Ludwig, H.F. & V. Lynch.
Ibid. 25, 692 (1953).

44. Oswald, W.J. & Gotaas, H.B.
Proc. Amer. Soc. Civil Engr. 81, 1 (1955).

45. Oswald, W.J., & Gotaas H.B.
Trans. Am. Soc. Civil. Engr. 122, 73-105(1957).

46. Oswald, W.J., Gotaas, H.B., Golueke, C.G. & W.R.Kellen.
Sew. Indus. Wastes 29, 437 (1957).

47. Oswald, W.J.
3rd Annual Sanitary Engineering Conference, Vanderbilt University, Nashville, Tennesse, May 26, 1964.

48. Others(Algology Section).
Studies on Oxidation Ponds carried out the Sewage Research Station of CPHERI, Benzon Bagh, Nagpur,1961.

49. Parabrahman, M. Kha, A.N., & J.S.S.Lakshminarayana.
Symposium on Crustacea held by the Marine Biol. Asson. at the Oceanographic Laboratory, University of Kerala, Ernakulam, India, on 12-15 June,1965, Abstracts p.31.

50. Parhad, N.M. & N.V.Rao,
Symposium on Waste Treatment by Oxidation Ponds held at CPHERI, Nagpur, India, on October 29-30, (1963).

51. Parker, C.D., H.L.John, & W.S.Taylor,
Sewage Ind. Wastes 22, 760 (1950).

52. Parker, C.D.,
J. Water, Poll. Contr. Feder. 34, 149-164 (1962).

53. Pratt, R., T.C.Daniels, and J.J.Eiler,
Science 99, 351 (1944).

54. Silva, P.L. & G.F.Papenfuss.
California State Water Poll. Board, Publi.No.7(1953).

55. Spoehr, H.A., J.H.C. Smith, H.H.Strain, H.W.Milner and G.H. Hardin.
Plant Physiol. 24; 120-149 (1949).

56. Standard Methods:
For the Examination of water, Sewage & Industrial Works. 11th Ed. (1960).

57. Suwannakarn V, & E. Gloyna.
Symposium on Waste Treatment by Oxidation Ponds held at CPHERI Nagpur, India on October 29-30(1963).

58. Thergaonkar, V.P.
Environmental Health, 5, 252-256 (1963).

59. Towne, W.W., Bartsch, A.R. & W.A. Davis.
Sewage Ind. Wastes, 29, 377-396 (1957).

60. U.S.D.H. E. & W.
A Joint Report with the N & S Dakota Depts. of Health. 1957.

61. Watanabe, A.
Arch. Bioch. Biophys. 34, 50-55 (1951).

62. Wennstrom, M.
Proc. U.N.Scientific Conference on conservation & Utilisation of Resources. Lake Success, N.Y. August 1949.

TABLE NO. I

Climatological Data for Ahmedabad.

For 1962 & 1963.

Season	Month	Temperature °C Mean				Monthly hours of bright sunshine	
		Max		Min			
		1962	1963	1962	1963	1962	1963
Cold-weather	December	29.2	29.5	13.4	15.1	289.7	273.2
"	January	27.8	26.3	9.5	12.3	307.8	292.0
"	February	31.5	33.6	14.6	14.7	273.2	286.5
Averages	-	29.5	29.8	12.5	14.0	290.2	283.9
Hot-weather	March	35.3	31.3	18.3	18.6	286.0	289.8
"	April	39.8	38.7	23.2	23.4	304.3	293.4
"	May	42.3	41.2	26.7	25.9	339.5	357.7
"	June	38.4	39.3	26.8	27.1	290.4	281.3
Averages	-	38.9	37.6	23.7	23.7	305.2	305.5
Monsoon	July	33.3	33.0	25.7	25.8	143.9	151.3
"	August	33.5	30.5	25.2	24.8	138.7	119.8
"	September	33.0	30.1	24.0	21.6	215.9	202.1
Averages	-	32.9	31.2	25.0	24.1	249.2	157.7
Post-monsoon	October	34.6	35.6	17.5	21.1	304.8	286.2
"	November	33.1	32.2	15.9	18.5	277.5	268.1
Averages	-	33.8	33.9	16.9	19.8	291.1	277.1

TABLE NO. 2

PHYSICO-CHEMICAL CONDITIONS OF RAW SEWAGE FEEDING THE SINGLE UNIT PILOT PLANT OXIDATION POND. MONTHLY AND SEASONAL AVERAGES

Month	Colour	Temp. °C	RESULTS EXPRESSED IN PARTS PER MILLION								
			5 day BOD at 20°C	Oxygen abs(4H)	D.O.	% Sat.	Phenol	ALKALINITY Total	Chlor.	Am-N	PO_4
July 1962	Grey	30.7	230	70	Nil	Nil	34	483	262	17.5	12.5
August 1962	"	31.4	292	58	"	"	21	486	281	19.8	10.0
September 1962	"	32.1	244	53	"	"	20	595	333	20.5	12.9
Average		31.4	255	60	"	"	25	521	292	19.3	11.8
October 1962	Black	31.0	158	62	"	"	28	689	341	19,4	12.5
November 1962	"	29.4	167	44	"	"	31	620	320	30.0	18.6
Average		30.2	162	53	"	"	29	654	330	24.7	15.5
December 1962	Black	25.9	120	30	"	"	21	623	380	24.1	16.9
January 1963	"	24.4	198	49	"	"	32	565	385	26.0	15.4
February 1963	"	27.4	208	60	"	"	70	654	316	28.8	17.4
Average		25.9	175	46	"	"	41	614	360	26.3	16.6
March 1963	"	29.0	208	49	"	"	32	558	325	24.6	12.9
April 1963	"	31.5	287	54	"	"	35	636	360	26.1	14.8
May 1963	"	33.1	183	61	"	"	50	554	312	27.1	15.4
June 1963	"	32.4	204	35	"	"	20	625	310	30.0	16.8
Average		31.5	220	48	"	"	34	593	327	21.9	15.0

TABLE NO. 2 (Contd.)

PHYSICO-CHEMICAL CONDITIONS OF RAW SEWAGE FEEDING THE SINGLE UNIT PILOT PLANT OXIDATION POND. MONTHLY AND SEASONAL AVERAGES

Month		Colour	Temp. °C	RESULTS EXPRESSED IN PARTS PER MILLION								
				5 day BOD at 20°C	Oxygen abs(4H)	D.O.	% Sat.	Phenol	ALKALINITY Total	ALKALINITY Chlor.	Am-N	PO_4
July	1963	Grey	31.2	168	49	Nil	Nil	48	560	320	28.0	17.4
August	"	"	31.7	160	39	"	"	48	520	290	25.6	19.0
September	"	"	31.1	178	26	"	"	Nil	620	260	21.0	14.8
Average			31.3	169	38	"	"	32	567	290	24.9	17.1
October	"	Black	31.6	186	36	"	"	35	562	292	20.6	11.4
November	"	"	30.9	190	43	"	"	40	594	353	17.0	12.6
December	"	"	28.2	200	49	"	"	28	560	342	18.4	10.8
Average			31.2	188	39	"	"	37	578	322	18.8	12.0

TABLE NO. 3

PHYSICO-CHEMICAL CONDITIONS OF THE FINAL EFFLUENT FROM THE SINGLE UNIT PILOT PLANT OXIDATION POND. MONTHLY AND SEASONAL AVERAGES.

Month		Colour	Temp. Oc	RESULTS EXPRESSED in parts per million						Chlor.	Am-N	PO_4
				5day BOD at 20°C	Oxygen abs(4H)	D.O.	% Sat	ALKALINITY Phenol.	ALKALINITY Total			
July	1962	D.Green	29.6	62	33	7.51	100.4	67	494	288	7.7	6.2
August	"	Green	30.2	52	34	4.00	52.9	36	500	274	8.0	4.5
September	"	P.Green	30.6	88	41	1.71	22.6	86	622	258	8.0	5.7
Average			30.1	67	36	4.40	58.6	63	539	273	7.9	5.5
October	1962	Green	26.1	36	32	7.62	115.7	78	685	441	4.8	8.6
November	"	Green-Br.	25.3	46	33	8.60	110.3	59	741	434	8.2	7.6
Average			25.7	41	32	8.11	113.0	69	713	442	6.5	8.1
December	1962	P.Green	24.0	33	33	5.92	59.6	84	701	436	12.1	7.3
January	1963	"	19.7	46	28	3.47	37.7	62	677	394	15.0	9.2
February	"	"	24.4	90	40	2.00	22.7	66	767	370	16.0	4.7
Average			22.7	56	37	3.80	40.0	71	715	400	14.4	7.1
March	1963	"	26.8	73	41	5.23	64.0	92	670	460	12.2	7.9
April	"	"	29.0	65	39	15.70	209.1	101	643	472	10.9	2.5
May	"	"	30.0	50	28	15.35	200.8	112	599	461	7.1	3.8
June	"	"	30.2	30	16	3.15	81.3	73	733	201	13.0	8.7
Average			29.0	54	31	9.86	138.8	94	661	398	10.8	5.7

TABLE NO.3 (Contd)

PHYSICO - CHEMICAL CONDITIONS OF THE FINAL EFFLUENT FROM THE SINGLE UNIT PILOT PLANT OXIDATION POND. MONTHLY AND SEASONAL AVERAGES

Month		Colour	Temp. 0c	Results expressed in parts per million								
				5 day BOD at 20oC	Oxygen abs (4.H)	D.O.	% St.	ALKALINITY		Chlor.	Am-N	PO_4
								Phenol.	Total			
July	1963	P.Green	29.0	45	32	5.51	71.8	87	643	332	15.8	8.0
August	"	"	28.9	29	21	4.62	59.9	49	505	356	16.0	8.9
September	"	"	31.1	29	30	10.42	141.7	52	717	278	10.6	6.4
Average			29.7	34	28	6.88	91.1	63	622	322	14.1	7.8
October	1963	"	29.2	54	25	5.66	77.3	62	566	284	10.4	8.3
November	"	Green	28.1	39	25	6.72	88.6	79	636	400	8.7	7.2
Average			28.6	46	25	6.19	82.9	70	601	342	9.5	7.7
December	"	Yell.	25.7	48	32	8.94	93.6	50	650	373	11.0	5.4

TABLE NO. 4

THE TOTAL NUMBER OF ORGANISMS RECORDED AS MONTHLY & SEASONAL AVERAGES; THE DOMINANT AND SUB-DOMINANT ORGANISMS EXPRESSED IN PERCENTAGES OF THE TOTAL IN THE FINAL EFFLUENT.

Month	Total No.of Organi-sms per ML x10^3	DOMINANT Name	% of the Total	SUB-DOMINANT Name	% of the Total
1962			1962		1962
July	452	Chlorella	90.0	Thiopedia rosea	4.0
				Ankistrodesmus	1.0
August	171	Chlorella	70.0	Thiopedia rosea	4.1
September	401	"	74.8	- do -	18.6
Average	341.3	-	-	-	-
October	69	Micractinium	81.3	Thiopedia rosea	9.1
November	91	Thiopedia rosea	62.2	Chlamydomonas	20.9
				Chroococcus	10.3
				Micractinium	4.3
Average	80.0	-	-	-	-
1963			1963		1963
January	1478	Chlorella	83.5	Thiopedia rosea	3.8
February	3981	Chlorococcum	60.1	- do -	31.8
Average	1922	-	-	-	-
March	3590	Chlorococcum	60.9	Thiopedia rosea	22.5
April	4724	Thiopedia rosea	55.9	Chlorella	35.1
		Chlorella	64.7	Chlamydomonas	13.0
		Micractinium	44.9	Thiopedia rosea	23.6
May	753	Micractinium	55.0	Oscillatoria	23.7
		Arthrospira	67.0	"	23.9
June	56	Thiopedia rosea	53.7	Arthrospira	31.4
		Arthrospira	64.1	Euglena	21.0
Average	2281	-	-	-	-
July	699	Thiopedia rosea	62.4	Chlorella	20.2
		Arthrospira	73.5	Chlorella	20.6
August	37	Thiopedia rosea	80.9	Oscillatoria	11.8
		Arthrospira	88.1	"	12.1
September	34	Thiopedia rosea	64.9	-	-
		Arthrospira	78.2	-	-
Average	257	-	-	-	-

Contd.......

1	2	DOMINANT 3		SUB-DOMINANT	
October	32	Arthrospira	77.8	Euglena	9.9
		Thiopedia rosea	90.0	Oscillatoria	13.6
November	2005	Chlorella	62.0	Thiopedia rosea	23.6
		Micractinium	77.9	-	-
Average	1018.5	-	-	-	-
December	1939	Chlorella	51.1	Thiopedia rosea	22.4

TABLE NO. 5

THE BACTERIAL COMPOSITION OF RAW SEWAGE AND THE FINAL EFFLUENT FROM THE SINGLE UNIT PILOT PLANT OXIDATION POND.

	COLIFORMS		E.COLI Type-I		FAECAL STREPTOCOCC		CITRATE UTILISERS	
	RAW SEWAGE	FINAL EFFLUENT	RAW SEWAGE	FINAL EFFLEUNT	RAW SEWAGE	FINAL EFFLUENT	RAW SEWAGE	FINAL EFFLUENT
1962								
July	$15x10^4$	80	$54x10^3$	16	$29x10^2$	3.4	---	-
August	$12x10^3$	65	90x10	22	50	0.37	$64x10^2$	174
September	$15x10^3$	73	$24x10^2$	14	93	0.91	$15x10^2$	114
Average	$59x10^3$	73	$191x10^2$	17	1014	1.6	3950	144
October	$92x10^3$	59	$53x10^2$	15	7.2	0.13	$61x10^2$	110
November	$45x10^3$	130	$35x10^3$	18	2.6	0.65	$12x10^3$	590
Average	$63.5x10^3$	94.5	20150	16.5	4.9	0.39	9050	350
December	$42x10^3$	310	$24x10^3$	110	2.9	0.52	$46x10^3$	910
1963								
January	$16x10^4$	170	$43x10^3$	140	82	0.40	$26x10^3$	120
February	$40x10^3$	940	$25x10^3$	510	92	2.30	$19x10^3$	430
Average	8666	473	$30.7x10^3$	253	59	1.07	$30.3x10^3$	487
March	$58x10^3$	75	$27x10^3$	54	430	2.10	$43x10^3$	1700
April	$88x10^4$	97	$81x10^4$	35	230	1.60	$25x10^4$	160
May	$61x10^4$	71	$29x10^4$	61	.99	0.29	$60x10^4$	58
June	$43x10^3$	81	$91x10^2$	50	7.3	0.03	$43x10^3$	460
Average	397750	81	289025	50	191	1.34	$234x10^3$	594
July	$25x10^4$	250	$14x10^4$	99	710	0.63	$59x10^4$	320
August	$20x10^4$	78	$11x10^4$	37	120	1.00	$61x10^3$	250
September	$32x10^4$	24	$17x10^4$	21	710	0.12	$31x10^4$	330
Average	$25.7x10^4$	117	$14x10^4$	52	513	0.28	32333	300
October	$15x10^5$	240	$31x10^4$	230	62	0.04	$13x10^5$	68
November	$46x10^5$	14	$24x10^5$	74	15	0.03	$24x10^5$	240
Average	$30.5x10^5$	127	$1355x10^3$	119	39	0.03	$18.5x10^5$	154
December	$13x10^4$	65	$93x10^3$	50	46	0.03	$46x10^5$	32